Evaluating Scientific Controversies: The Influence of Beliefs Regarding the Uncertainty of Knowledge and Cognitive Engagement

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ABSTRACT

Scientific controversies are abundant in the modern-day knowledge society. Individuals are increasingly confronted with multiple and contradictory scientific knowledge claims pertaining to issues that are relevant for their personal lives. Hence, in order to make informed decisions individuals must be able to evaluate the conflicting information they encounter in scientific controversies. Whereas a direct (i.e., first-hand) evaluation of the underlying causes of a scientific controversy is usually not possible for laypeople, research has identified several factors that are beneficial for successful indirect (i.e., second-hand) evaluation of scientific controversies.

The present dissertation combined two prominent and emerging constructs in educational research to explain individuals' (second-hand) evaluation of scientific controversies: epistemic beliefs and engagement. Epistemic beliefs refer to individuals' perceptions of knowledge and knowing. The present dissertation focused on beliefs regarding the uncertainty of knowledge (or uncertainty beliefs), that is, individuals' beliefs that knowledge is either tentative and evolving or absolute and fixed. Engagement, on the other hand, refers to individuals' commitment or effort regarding a learning task or activity. The present dissertation investigated cognitive engagement, which can be defined as the effortful investment of mental resources during a task. Several theoretical models as well as empirical evidence suggest that both of these variables, uncertainty beliefs and cognitive engagement, are particularly relevant for the evaluation of scientific controversies. Moreover, epistemic belief research has emphasized the importance of engagement when individuals are confronted with contradictory information, and in engagement research epistemic beliefs are assumed to have a strong influence. Surprisingly, however, these two research areas have not yet been integrated. Furthermore, past research has mainly focused on single aspects of the respective constructs, whereas it must be assumed that both uncertainty beliefs and cognitive engagement are multifaceted constructs including trait-like and state-like aspects.

Three empirical studies were conducted to address these issues and to advance the understanding of how individuals evaluate scientific controversies. Using multiple indicators based on offline measures (e.g., questionnaires) and online measures (e.g., eye tracking), data from two samples of $N = 44$ and $N = 40$ university students was collected.

Study 1 investigated the combined influence of uncertainty beliefs and cognitive engagement on students' evaluations of scientific controversies. Uncertainty beliefs were assessed in a preceding online questionnaire, and cognitive engagement was measured using a pupil dilation

measure. This measure was provided by eye-tracking technology while participants were working on an evaluation test that consisted of different scientific controversies in the lab. Results showed that both uncertainty beliefs and cognitive engagement were positively correlated with participants' results in the controversy-evaluation test. Moreover, the relation between uncertainty beliefs and the controversy-evaluation test was partly mediated by cognitive engagement.

Study 2 had the aim of differentiating multiple indicators of cognitive engagement and their relation to the evaluation of scientific controversies. Specifically, general cognitive engagement was assessed in a preceding online questionnaire, self-reported situational cognitive engagement was assessed repeatedly during the abovementioned controversy-evaluation test using a single-item measure, and process-related situational cognitive engagement was assessed with fixation time measures and the same pupil dilation measure as used in Study 1. Results showed that general and situational measures of cognitive engagement were not correlated, but a negative correlation self-reported and process-related situational cognitive engagement was found. Furthermore, general and situational cognitive engagement were differentially related to other variables. Whereas general cognitive engagement was related to motivational variables and evaluation outcomes, situational cognitive engagement was related to reading comprehension ability.

Finally, *Study 3* investigated different facets of uncertainty beliefs and their relation to evaluating scientific controversies. To measure participants' professed uncertainty beliefs, the same preceding online questionnaire was used as in Study 1. Enacted uncertainty beliefs were measured with a verbalization technique in which participants retrospectively verbalized what they thought when working on the controversy-evaluation test guided by a recording of their own eye movements. Results revealed that professed and enacted uncertainty beliefs were correlated, and that both variables predicted evaluation outcomes. Furthermore, the relation between professed uncertainty beliefs and the controversy-evaluation test was partly mediated by enacted uncertainty beliefs.

The present dissertation provides both a broader and a deeper understanding of the investigated constructs by combining separate research traditions and integrating innovative measurement approaches. The findings of the three studies are discussed in a broader context, both regarding the conceptualization of the investigated constructs in research as well as the relevance of uncertainty beliefs and cognitive engagement in the light of scientific controversies for science education and beyond.

ZUSAMMENFASSUNG

Wissenschaftliche Kontroversen sind allgegenwärtig in der heutigen Wissensgesellschaft. Personen sind mehr und mehr mit gegensätzlichen Wissensbehauptungen zu wissenschaftlichen Fragestellungen konfrontiert, die für ihr persönliches Leben relevant sind. Um fundierte Entscheidungen treffen zu können müssen Personen daher fähig sein, die konfligierenden Informationen zu bewerten, denen sie in wissenschaftlichen Kontroversen ausgesetzt sind. Die direkte Bewertung (d.h. die Bewertung aus erster Hand) zugrundeliegender Ursachen für wissenschaftliche Kontroversen ist für Laien zwar üblicherweise nicht möglich. Jedoch hat die Forschung verschiedene Faktoren ermittelt, die vorteilhaft für die indirekte Bewertung (d.h. die Bewertung aus zweiter Hand) wissenschaftlicher Kontroversen sind.

Die vorliegende Dissertation kombinierte zwei prominente und aufstrebende Konstrukte der Bildungsforschung, die die Bewertung wissenschaftlicher Kontroversen (aus zweiter Hand) von Personen erklären können: epistemische Überzeugungen und *Engagement*. Epistemische Überzeugungen beziehen sich auf die Annahmen von Personen zu Wissen und Wissenserwerb, und die vorliegende Dissertation befasste sich mit Überzeugungen bezüglich der Unsicherheit von Wissen (oder Unsicherheitsüberzeugungen), das heißt die Überzeugungen von Personen ob Wissen vorläufig und veränderlich oder absolut und statisch ist. Engagement bezieht sich wiederum auf die Bemühung oder Anstrengung von Personen bezüglich einer Lernaufgabe oder Aktivität. Die vorliegende Dissertation untersuchte kognitives Engagement, was als der angestrengte Einsatz mentaler Ressourcen während einer Aufgabe definiert werden kann. Verschiedene theoretische Modelle sowie empirische Befunde deuten darauf hin, dass beide Variablen (Unsicherheitsüberzeugungen und kognitives Engagement) für die Bewertung wissenschaftlicher Kontroversen besonders relevant sind. Darüber hinaus hat die Forschung zu epistemischen Überzeugungen die Bedeutung von Engagement hervorgehoben, wenn Personen mit widersprüchlichen Informationen konfrontiert sind, und in der Forschung zu Engagement gelten epistemische Überzeugungen als einflussreicher Faktor. Es ist jedoch überraschend, dass diese beiden Forschungsbereiche bisher nicht kombiniert wurden. Zudem hat sich die Forschung bisher hauptsächlich mit einzelnen Aspekten der jeweiligen Konstrukte befasst, wobei aber angenommen werden muss, dass sowohl Unsicherheitsüberzeugungen als auch kognitives Engagement facettenreiche Konstrukte sind, die sowohl Trait- als auch State-Aspekte beinhalten.

Drei wissenschaftliche Studien wurden durchgeführt, um diese Fragestellungen anzugehen und um das Verständnis dazu, wie Personen wissenschaftliche Kontroversen bewerten, zu erweitern. Mit Indikatoren, die auf Offline-Maßen (z.B. Fragebögen) und Online-Maßen (z.B.

Eyetracking) beruhen, wurden Daten bei zwei studentischen Stichproben aus je $N = 44$ und $N = 40$ Personen erhoben.

Studie 1 untersuchte den gemeinsamen Einfluss von Unsicherheitsüberzeugungen und kognitivem Engagement auf die Bewertung wissenschaftlicher Kontroversen von Studierenden. Unsicherheitsüberzeugungen wurden in einem vorangehenden Onlinefragebogen erfasst, und kognitives Engagement wurde durch ein Pupillenerweiterungsmaß mittels Eyetracking-Technologie erfasst, während die Versuchspersonen im Labor einen Evaluationstest bearbeiteten, der aus verschiedenen wissenschaftlichen Kontroversen bestand. Die Ergebnisse zeigten, dass sowohl Unsicherheitsüberzeugungen als auch kognitives Engagement positiv mit dem Ergebnis des Evaluationstests korrelieren. Darüber hinaus wurde der Zusammenhang zwischen Unsicherheitsüberzeugungen und dem Evaluationstest teilweise durch kognitives Engagement mediiert.

Studie 2 hatte zum Ziel, verschiedene Indikatoren von kognitivem Engagement und deren Einfluss auf die Bewertung wissenschaftlicher Kontroversen zu differenzieren. Konkret wurde allgemeines kognitives Engagement in einem vorangehenden Onlinefragebogen erfasst. Selbstberichtetes situationales kognitives Engagement wurde wiederholt während des oben genannten Evaluationstests anhand eines einzelnen Items erfasst. Prozessbezogenes situationales kognitives Engagement wurde durch Maße der Fixationsdauer sowie durch dasselbe Pupillenerweiterungsmaß wie in Studie 1 erhoben. Die Ergebnisse zeigten, dass allgemeines und situationales kognitives Engagement nicht korrelierten. Es wurde jedoch eine negative Korrelation zwischen selbstberichtetem und prozessbezogenem situationalem kognitiven Engagement gefunden. Weiterhin hingen allgemeines und situationales kognitives Engagement unterschiedlich mit anderen Variablen zusammen. Während allgemeines kognitives Engagement mit motivationalen Variablen und Evaluationsergebnissen korrelierte, hing situationales kognitives Engagement mit Leseverständnis zusammen.

Studie 3 untersuchte schließlich verschiedene Facetten von Unsicherheitsüberzeugungen und ihren Bezug zur Bewertung wissenschaftlicher Kontroversen. Die „erklärten" Unsicherheitsüberzeugungen der Versuchspersonen wurden anhand desselben vorangehenden Onlinefragebogens wie in Studie 1 erhoben. Die „aktivierten" Unsicherheitsüberzeugungen wurden mit einer Verbalisierungsmethode erhoben, in welcher die Versuchspersonen retrospektiv das verbalisierten, was sie während der Bearbeitung des Evaluationstests dachten, wobei eine Aufzeichnung ihrer eigenen Augenbewegungen als Hinweisreiz diente. Die Ergebnisse zeigten, dass erklärte und aktivierte Unsicherheitsüberzeugungen korrelierten, und dass beide Variablen die Leistung im Evaluationstest vorhersagten. Außerdem wurde der

Zusammenhang zwischen erklärten Unsicherheitsüberzeugungen und dem Evaluationstest teilweise durch aktivierte Unsicherheitsüberzeugungen mediiert.

Die vorliegende Dissertation bietet sowohl ein breiteres als auch ein vertieftes Verständnis der untersuchten Konstrukte, indem sie bis dato getrennte Forschungstraditionen integriert und innovative Messmethoden miteinander verbindet. Die Ergebnisse der drei Studien werden in einem breiteren Kontext diskutiert, sowohl hinsichtlich der Konzeptualisierung der untersuchten Konstrukte in der Forschung als auch in Bezug auf die Relevanz von Unsicherheitsüberzeugungen und kognitivem Engagement für naturwissenschaftlichen Unterricht und darüber hinaus.

CONTENTS

1

Introduction and Theoretical Framework

1 Introduction and Theoretical Framework

In April 2017, researchers from all over the world followed a call to join a “march for science,” in which they demonstrated against the disparagement of scientific findings and the propagation of so-called alternative facts, amongst other things.[1] Many of the demonstration posters they carried exhibited phrases such as “there is no alternative to facts” or “stick to the truth.” Whereas these phrases could be viewed as deliberate exaggerations that were intended to take a stance against populism, they also conveyed a somewhat problematic message. They implied that science offers unambiguous, unchanging, and absolute facts. With this image of science, laypeople are unlikely to apprehend the uncertainty of scientific knowledge, let alone engage in the critical evaluation of competing scientific claims (Howitt & Wilson, 2018; Lederman & O'Malley, 1990). However, from large paradigmatic changes down to specific research topics, science is hardly ever certain, and new findings can challenge what was once considered to be true (Carey & Smith, 1993; Goldman & Scardamalia, 2013). In our modern-day knowledge society, the construction of meaning often entails the comparison of multiple sources, offering conflicting or even contradictory information (Bråten & Strømsø, 2010; Goldman, 2004). As a result, scientific controversies, that is, conflicting viewpoints on a given scientific issue held by multiple experts or sources, are highly salient, even for laypeople. The availability of a multitude of scientific knowledge claims on the Web intensifies this ambiguity even further (Alexander, 2012; Goldman & Brand-Gruwel, 2018; Salmerón, Kammerer, & Delgado, 2018; Strømsø & Kammerer, 2016). If laypeople believe that scientific knowledge is certain, they are likely to accept those positions among competing stances that are in line with their prior beliefs (Maier & Richter, 2013; Whitmire, 2004), or they will not even invest effort in comparing different sources (Kuhn, 2005; Salomon, 1983), leading to a fragmentary or one-sided understanding of scientific information. The problems that arise are not only academic in nature. Science bears important implications for everyday life decisions in sectors such as technology, health, and education (Greene & Yu, 2016; Sandoval, 2005; Sinatra, Kienhues, & Hofer, 2014). As a consequence, the ability to evaluate controversial scientific information is an important prerequisite for the democratic participation of individuals (Hess, 2008; OECD, 2007; Roth & Lee, 2004; Sandoval, 2005; Sinatra & Hofer, 2016).

For example, the manner in which an individual evaluates the recent controversy over the harmfulness of diesel vehicles in Germany might not only influence what kind of car he or she

[1] https://www.marchforscience.com/

is going to buy but also which political party the person will elect on the basis of each party's respective vehicle policies. Yet how are laypeople to make good use of scientific knowledge if this knowledge is presented as inconsistent and contradictory? Generally speaking, in order to understand a scientific controversy, individuals have to be able and willing to identify its underlying causes (Kolstø et al., 2006; Stadtler & Bromme, 2014; Thomm, Barzilai, & Bromme, 2017; Thomm, Hentschke, & Bromme, 2015). Only then can they develop scientific literacy in the sense that they are able to differentiate between more and less valid scientific knowledge claims and make more informed decisions (Aikenhead, Orpwood, & Fensham, 2011; Britt, Richter, & Rouet, 2014; Carey & Smith, 1993; Feinstein, 2011; Tabak, 2018). It is therefore not surprising that evaluating scientific controversies also plays a central role in research on critical thinking (Angeli & Valanides, 2009; Jiménez-Aleixandre & Puig, 2012) and scientific reasoning (Burbules & Linn, 1988; Lawson, 2004). Coming back to the aforementioned "march for science" demonstrations, a scientifically literate spectator might not be happy with the claim that science, as a coherent whole, will offer absolute truth, as some of the posters had implied. Rather, he or she might ask which experts can make justified claims about a given scientific issue and why.

In this regard, Bromme and colleagues differentiated between first- and second-hand evaluations of scientific knowledge claims (Bromme & Goldman, 2014; Bromme, Thomm, & Wolf, 2013). First-hand evaluation (i.e., asking "What is true?") refers to evaluating the veracity of a knowledge claim oneself, for example, by conducting empirical studies, or by drawing on prior knowledge or "folk science". However, in most cases, laypeople and scientists alike must engage in second-hand evaluation (i.e., asking "Whom to believe?"), that is, in identifying and evaluating the veracity of knowledge claims in areas that are beyond their own expertise. Particularly in the domain of science, individuals are at risk of developing naïve perceptions because knowledge in this domain is often perceived as consisting of absolute facts rather than of models and approximations of natural phenomena (Hofer, 2000; Limón, 2006; Mason, 2010; Thomm & Bromme, 2016). In order to provide individuals with more sophisticated ways of dealing with scientific knowledge, a number of factors associated with proficient second-hand evaluation have previously been investigated. For example, studies have demonstrated the importance of source evaluation (i.e., paying attention to source features such as expertise or trustworthiness) when individuals evaluate controversial scientific information (Barzilai, Tzadok, & Eshet-Alkalai, 2015; Bråten, Stadtler, & Salmerón, 2018; Kammerer, Bråten, Gerjets, & Strømsø, 2013; Kammerer, Meier, & Stahl, 2016). Among other aspects linked to second-hand evaluation are textual features of science-related documents such as text structure or difficulty (Ariasi & Mason, 2011; Scharrer, Britt, Stadtler, & Bromme, 2013; Thomm & Bromme, 2012), reading goals (Stadtler, Scharrer, Skodzik, & Bromme, 2014; Trevors & Muis, 2015), or reader characteristics such as prior attitudes or knowledge (Ho, Tsai, Wang, & Tsai, 2014; Salmerón, Kammerer, & García-Carrión, 2013; van Strien, Brand-Gruwel, & Boshuizen, 2014).

Beyond these factors, there are two research areas that appear particularly relevant for the evaluation of scientific controversies (i.e., second-hand evaluation of competing knowledge claims). First, individuals' epistemic beliefs (i.e., their beliefs about knowledge and knowing) have been shown to influence how contradictory information is addressed, processed, and evaluated (Bråten et al., 2011; Ferguson, Bråten, & Strømsø, 2012; Garrett & Weeks, 2017; Kardash & Scholes, 1996; Mason & Boscolo, 2004). Second, individuals' cognitive engagement (i.e., the mental resources they invest) has been shown to affect reasoning processes and outcomes when individuals are confronted with contradictory information. (Alongi, Heddy, & Sinatra, 2016; Dole & Sinatra, 1998; List & Alexander, 2017).

This dissertation integrates these two constructs: epistemic beliefs (particularly beliefs regarding the uncertainty of knowledge) and cognitive engagement when individuals evaluate scientific controversies. Prior research has failed to combine these two research fields, even though they do not seem to work well without each other. On the one hand, enacting one's beliefs regarding the uncertainty of knowledge can be considered an effortful process that requires cognitive engagement (DeBacker & Crowson, 2006; Hofer, 2004b). Indeed, in epistemic belief research it has often been implied that cognitive engagement would have a strong influence on how individuals make use of their beliefs (e.g., Bendixen & Rule, 2004; Kuhn, 2005). On the other hand, merely exerting cognitive engagement without the guidance of an underlying belief system such as beliefs regarding the uncertainty of knowledge is not likely to be adaptive if readers want to evaluate conflicting scientific information in a goal-directed and strategic process (Kuhn, Arvidsson, Lesperance, & Corprew, 2017; Rastegar, Jahromi, Haghighi, & Akbari, 2010). Consequently, in engagement research it has been assumed that variables such as beliefs regarding the uncertainty of knowledge are necessary for successful cognitive engagement (Sinatra, Heddy, & Lombardi, 2015). Despite all these theoretical assumptions, past research on epistemic beliefs and engagement has mainly gone separate ways. In consequence, the usefulness of beliefs regarding the uncertainty of knowledge for cognitive engagement (and vice versa) was left unexploited. Presumably, integrating these variables would offer valuable insights in the sense that both beliefs regarding the uncertainty of knowledge and cognitive engagement can be seen as an auxiliary variable for the functionality of the other in order to explain how individuals evaluate scientific controversies. The metaphor that comes to mind is that of a car: Whereas no car can run without an engine (cognitive engagement), steering the car to a certain destination also requires a map (e.g., uncertainty beliefs), especially if the terrain (topic or task) is unfamiliar.

Herein lies the unique contribution of the present dissertation: It integrates epistemic belief research and cognitive engagement research in order to advance the understanding of how individuals evaluate scientific controversies. Moreover, the dissertation offers a fine-grained analysis of different facets of these two constructs by triangulating traditional offline measures such as questionnaires and innovative online measures such as eye tracking and verbal reports. This fine-grained, in-depth investigation is pivotal for a clearer conceptual understanding of the examined constructs. Specifically, by differentiating trait-like aspects and state-like aspects of beliefs regarding the uncertainty of knowledge as well as cognitive engagement, the present dissertation offers possible explanations for how these constructs situate and operate against the background of different contextual demands. For example, how do individuals who espouse beliefs in uncertain knowledge enact these beliefs when they are confronted with contradictory information? How does their general, self-reported cognitive engagement relate to situational cognitive engagement when individuals complete an evaluation task? These differentiations provide an essential extension of prior research which can only be achieved by the integration of previously unconnected research traditions and their respective theories and methods. In doing so, the dissertation aims to build a bridge between educational and cognitive research because it still appears that "although the collaboration between educational measurement specialists and cognitive psychologists should work easily in principle, in practice the collaboration has not been as productive as once anticipated" (Leighton, 2004, p. 13). The following sections discuss the relevance of epistemic beliefs regarding the uncertainty of knowledge (see 1.1) and cognitive engagement (see 1.2) in the context of evaluating scientific controversies. After that, the conceptual overlap between the two constructs (see 1.3) and the resulting research questions addressed in this dissertation (see 1.4) are presented.

1.1 Epistemic Beliefs

The beliefs individuals hold, defined as the extents to which certain propositions are evaluated as true (Wolfe & Griffin, 2018), have a great impact on how information is processed and evaluated (Britt et al., 2014). This is particularly the case for epistemic beliefs (from ancient Greek *epistēmē*, meaning "knowledge"), which refer to individuals' perceptions of the structure of knowledge and the process of knowing (Hofer & Bendixen, 2012; Hofer & Pintrich, 1997; Sandoval, Greene, & Bråten, 2016). Epistemic beliefs have been described as "filters, frames, and guides" (Fives & Buehl, 2017, p. 35) or lenses through which learners approach a task (Bromme, Pieschl, & Stahl, 2010). Because they address beliefs about how and why people come to know something, epistemic beliefs can be referred to as meta-knowledge (Barzilai & Zohar, 2014, 2016; Hofer, 2004b). The prerequisite for epistemic beliefs is the formation of a theory of mind, which eventually leads to an understanding that representations of knowledge can differ across individuals (Iordanou, 2016; Sodian & Kristen, 2016; Wildenger, Hofer, & Burr, 2010).

1.1.1 Conceptualizations of epistemic beliefs

Two major lines of educational research have investigated the roles of epistemic beliefs in learning and achievement: a developmental approach and a belief system approach. The developmental approach dates back to Perry (1970), who studied how students acquire knowledge and claimed that they progress through different stages from naïve to increasingly complex perceptions. In this regard, common to most conceptualizations in this line of research is a trajectory involving absolutist, multiplist, and evaluativist stages (e.g., Kuhn, 1991; Kuhn, Cheney, & Weinstock, 2000). Individuals holding an absolutist view believe that knowledge is either right or wrong. The next developmental step is a multiplist view, where conflicting knowledge claims can coexist. Finally, individuals holding an evaluativist view acknowledge that there is no absolute knowledge, but they evaluate and weigh different knowledge claims on the basis of valid criteria such as supporting evidence (Kuhn, 2001). In their reflective judgment model, King and Kitchener (1994, 2004) presented a similar framework in which they differentiated three stages of prereflective, quasireflective, and reflective thinking.

A second line of research, the belief system approach, conceptualizes epistemic beliefs as a set of relatively independent dimensions (e.g., Schommer-Aikins, 2002, 2004; Schraw, Bendixen, & Dunkle, 2002). This multidimensional framework comes along with a different approach to the assessment of individuals' epistemic beliefs. Whereas in the developmental approach, researchers usually employ structured interviews to assess the sophistication of individuals' epistemic stances, proponents of the belief system approach have developed standardized questionnaires that allow for a psychometric analysis of individuals' belief system and the relations of this system to other relevant variables (e.g., Conley, Pintrich, Vekiri, & Harrison, 2004; Schommer, 1990). In their seminal literature review, Hofer and Pintrich (1997) concluded that epistemic beliefs can be fundamentally divided into two dimensions: the nature of knowledge and the nature of knowing. First, the nature of knowledge comprises the subdimensions simplicity of knowledge and certainty of knowledge. The simplicity dimension ranges from the belief that knowledge is complex and interrelated to the belief that knowledge is composed of isolated facts. The certainty dimension ranges from viewing knowledge as tentative and evolving to viewing knowledge as absolute and unchanging (see also Hofer, 2000). Second, the nature of knowing comprises the subdimensions source of knowledge and justification for knowing. The source dimension ranges from viewing knowledge as actively constructed by the self to viewing knowledge as solely transmitted by external authorities. Finally, the justification dimension differentiates between taking scientific experiments and data into account as opposed to relying on mere observation or intuition.

Among the main conceptual differences between the developmental approach and the belief system approach is that the former proposes a systematic progression toward more advanced beliefs, whereas the latter posits that individuals may show different manifestations in different belief dimensions (Sandoval et al., 2016). Moreover, research that is in line with the developmental approach has usually investigated factors that contribute to the development of epistemic beliefs, whereas research that is in line with the belief system approach has used epistemic beliefs as independent variables to explain subsequent learning processes (Aditomo, 2017). However, a study by Barzilai and Weinstock (2015) suggested that the two conceptualizations are not distinct but rather that the different facets are intertwined, with the certainty dimension and a combined source/justification dimension serving as lower-order factors of the developmental stages of absolutism, multiplism, and evaluativism.

Hence, beliefs about the uncertainty of knowledge (hereafter referred to as uncertainty beliefs) can be considered a central component of both epistemic belief approaches (see also Conley et al., 2004; King & Kitchener, 1994; Schommer, 1990; Trautwein & Lüdtke, 2007). For example, in line with the developmental approach, the reflective judgment model (King & Kitchener, 1994, 2004) depicts a process of development that moves from beliefs in certain knowledge to more advanced beliefs in uncertain, complex, and contextual knowledge. Similarly, proponents of the belief system approach have identified the important role of the certainty dimension in terms of the tentativeness of knowledge (e.g., Schommer, 1990), and Bromme, Kienhues, and Stahl (2008) concluded that epistemic beliefs "in their very core always refer to the question of certainty (or validity, viability, truthfulness) of assertions about certain topics" (p. 429). Prior research has shown that uncertainty beliefs are related to positive attitudes toward science (Fulmer, 2014) as well as to better school grades and students' choice of study in a STEM (science, technology, engineering, and mathematics) domain (Trautwein & Lüdtke, 2007). In line with all the approaches that have been discussed here, central to uncertainty beliefs is whether individuals assume that there is always a "right answer" or whether they recognize that there may be conflicting and even contradictory knowledge claims that can be more or less valid depending on certain criteria such as the validity of explanations or the quality of arguments (Britt et al., 2014). Given the relevance of uncertainty beliefs for how individuals approach competing knowledge claims, the focus on this epistemic belief dimension in this dissertation was driven by the notion that individuals with beliefs in uncertain (or certain) knowledge should be well (or poorly) equipped to evaluate scientific controversies (Kirch, 2012).

1.1.2 Professed versus enacted epistemic beliefs

In prior research, individuals' uncertainty beliefs (and other epistemic belief dimensions) have either been assessed in a relatively general and abstract manner or directly during a specific task. The former approach has been criticized by some for providing mainly decontextualized measures, which might be inappropriate when studying complex tasks such as the evaluation of scientific controversies because such tasks are influenced by many contextual factors (Muis, Duffy, Trevors, Ranellucci, & Foy, 2014; Sinatra & Chinn, 2012). For instance, the fact that readers hold strong uncertainty beliefs in general does not necessarily mean that they will adapt their reasoning accordingly during tasks in which their beliefs are called upon, such as reading conflicting scientific sources. In their epistemological resources approach, Elby and Hammer (2010) go as far as to claim that only contextual features can explain a person's current epistemic cognition, operating in so-called epistemological frames. Others have challenged this view by stating that individuals' relatively stable epistemic beliefs influence their epistemic cognition in a given context (Kienhues, Ferguson, & Stahl, 2016; Sinatra et al., 2014). In line with this reasoning, Pintrich (2002) stated that "it is logical that as individuals grapple with the nature of knowledge and knowing, their cognitions and beliefs about how knowledge is acquired and how people learn or come to understand ideas are also activated or evoked" (p. 391). This idea is shared by several authors who differentiated between epistemic beliefs and epistemic cognition (e.g., Hofer, 2001; Pieschl, Stahl, & Bromme, 2013; Sinatra & Chinn, 2012). Hofer (2001), for example, proposed that epistemic beliefs might be "activated in context, operating as epistemic cognition" (p. 377). Table 1.1 summarizes different terms used in the literature to distinguish between epistemic beliefs and epistemic cognition. The different terms share the notion that epistemic beliefs refer to individuals' relatively stable underlying belief system regarding the nature of knowledge and knowing, whereas epistemic cognition concerns the activation or application of these beliefs in a given context (see also Chinn, Buckland, & Samarapungavan, 2011). Borrowing from Louca, Elby, Hammer, and Kagey (2004), the present dissertation differentiates between professed uncertainty beliefs (i.e., individuals' general, underlying beliefs regarding the uncertainty of knowledge) and enacted uncertainty beliefs (i.e., individuals' epistemic cognition regarding the uncertainty of knowledge in a given context). The deliberations presented above recently cumulated in the Handbook of Epistemic Cognition, stating that "epistemic beliefs are the content upon which epistemic cognition processes act" (Greene, Sandoval, & Bråten, 2016a, p. 5). However, empirical investigations of this proposition are still missing. A small body of mostly qualitative studies in the science education literature has documented differences between teachers' or students' self-reported beliefs and their enacted classroom practices, attributing these differences to situational constraints (Berland & Crucet, 2016; Salter & Atkins, 2014; Tobin & McRobbie, 1997). Besides, one empirical study by Mason, Boldrin, and Ariasi (2010a) investigated the relation between professed and enacted uncertainty beliefs. The authors first assessed 8th grade students' professed uncertainty beliefs using Conley et al.'s (2004) self-report measure on scientific

Table 1.1

Differentiation between epistemic beliefs and epistemic cognition in the literature

	Concept of epistemic beliefs	**Concept of epistemic cognition**
Hogan (2000)	distal epistemology	proximal epistemology
Louca, Elby, Hammer, and Kagey (2004)	professed epistemic beliefs	enacted epistemic beliefs
Sandoval (2005)	formal epistemology	practical epistemology
Chai and Khine (2008)	espoused beliefs	beliefs in practice
Bråten, Britt, Strømsø, and Rouet (2011)	self-reported epistemic beliefs	epistemic beliefs in action
Greene and Yu (2016)	epistemic dispositions and beliefs	epistemic cognition skills
Alexander (2016)	beliefs espoused	beliefs enacted

epistemic beliefs. Then, they had participants perform a Web search on the topic of dinosaur extinction, and their enacted uncertainty beliefs were assessed during retrospective interviews with the question “How stable over time do you think the information you found on the Internet is?”. Mason et al. (2010a) found a positive correlation between professed uncertainty beliefs and enacted uncertainty beliefs (which they referred to as epistemic metacognition). However, whereas the measure of professed uncertainty beliefs related to the tentativeness of knowledge, the measure of enacted uncertainty beliefs related to the stability of knowledge. The fact that the two measures related to slightly different aspects of uncertainty beliefs complicates a clear-cut interpretation of the results.

In conclusion, little is known about the interrelation between professed and enacted uncertainty beliefs. On that note, Alexander (2016) identified the relation between professed and enacted uncertainty beliefs (and other epistemic belief dimensions) as one of the big unresolved research questions in the field (see also Schraw & Olafson, 2003). Rather than choosing one of these conceptualizations over the other, more research on the interplay of epistemic beliefs and epistemic cognition is needed (Hofer, 2016; Hofer & Sinatra, 2010; Kienhues et al., 2016; Song, Hannafin, & Hill, 2007). The present dissertation addresses this issue by integrating professed uncertainty beliefs and enacted uncertainty beliefs in the context of scientific controversies. The following sections discuss the role of uncertainty beliefs in the evaluation of scientific controversies, both in terms of relevant theoretical frameworks (see 1.1.3) and empirical findings (see 1.1.4).

1.1.3 Theoretical frameworks regarding epistemic beliefs and the evaluation of scientific controversies

Scientific controversies can be conceptualized as multiple conflicting documents or sources. In this regard, Perfetti, Rouet, and Britt (1999) introduced the documents model framework which accounts for the representation and integration of multiple information sources. The first feature that constitutes a documents model is called the intertext model, in which relations between different sources as well as relations between sources and content are represented. These source-source links and source-content links manifest themselves in so-called document nodes. A document node represents a reader’s source or text-based assumptions about a certain document. Second, Perfetti et al. (1999) introduced the situations model as a knowledge structure that combines related information across several texts, forming a substrate of multiple individual situation models.

Building on this, Bråten et al. (2011) proposed a theoretical framework in which they discussed the role of epistemic beliefs for the construction of the documents model. This framework specifies empirically based links between the four epistemic belief dimensions (source, justification, simplicity, and certainty of knowledge) introduced by Hofer and Pintrich (1997) and the two components of the documents model (intertext model and situations model) proposed by Perfetti et al. (1999). Figure 1.1 illustrates Bråten et al.'s (2011) model by using the controversy about climate change with four conflicting documents on the causes and consequences of global warming as an example. The intertext model is represented by multiple documents in ovals, which are connected by dashed lines. The situations model entails different causes and consequences of climate change, represented by boxes and connected by solid lines.

Even though Bråten et al. (2011) proposed links between all four epistemic belief dimensions and the documents model, it seems plausible that in the context of evaluating scientific controversies, uncertainty beliefs are particularly influential. By contrast, the source and justification dimensions refer to whether individuals recognize knowledge that they did not generate themselves (source beliefs) and whether they view scientific evidence as a valid source of information (justification beliefs). Hence, these dimensions seem more suited for explaining

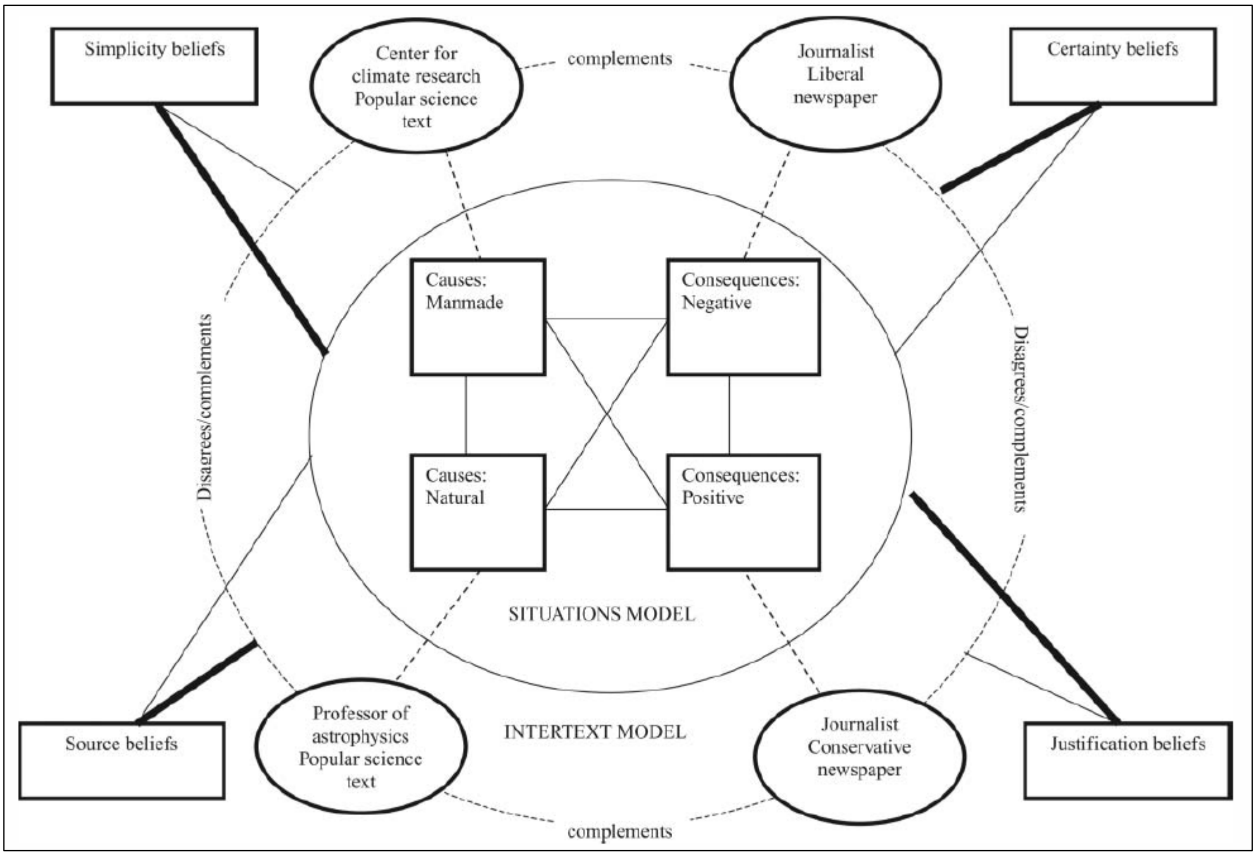

Figure 1.1 *Integrated model of epistemic beliefs and documents model (Bråten, Britt, Strømsø, & Rouet, 2011, p. 57)*

whether individuals take scientific information into account in the first place rather than for explaining how individuals compare different scientific sources. Furthermore, the simplicity dimension refers to whether information is perceived as isolated and fragmented or whether readers try to integrate information into a coherent representation. However, aiming at immediate integration might prevent readers from comprehending the significance of different viewpoints as well as the underlying causes of a controversy. Only after the juxtaposition of different viewpoints as implied by uncertainty beliefs can readers make decisions about the extent to which these viewpoints can be integrated into a more differentiated mental representation (see also Britt, Rouet, & Braasch, 2013). Specifically, Bråten et al. (2011) suggested that uncertainty beliefs should be particularly important for the construction of an intertext model because readers' task perception differs in accordance with their uncertainty beliefs. A reader who believes that knowledge is tentative and evolving (i.e., one who holds strong uncertainty beliefs) might be more apt to juxtapose and integrate inconsistent information sources on a given issue, whereas a reader who believes that knowledge is absolute and unchanging (i.e., one who holds weak uncertainty beliefs) might perceive that the task is to identify the information source that provides the correct answer (Bråten et al., 2011). Accordingly, readers with weak uncertainty beliefs will likely process the provided information superficially, whereas readers holding strong uncertainty beliefs might engage in more strategic processing of complex and contradictory information. Bråten et al. (2011) also pointed out the relevance of uncertainty beliefs for the construction of a situations model. The authors argued that when knowledge pertaining to a controversial issue is considered tentative and evolving, readers might draw more elaborated cross-text comparisons in order to corroborate consistent and discrepant information and thus develop a more integrated understanding of the information spread across different texts. That said, individuals' uncertainty beliefs might influence whether contradictory information is immediately rejected or whether individuals develop a more advanced mental representation that takes into account opposing viewpoints.

More recently, List and Alexander (2019) introduced another framework for multiple source use. Even though the role of epistemic beliefs is not as fully differentiated in their framework as in the Bråten et al. (2011) model, the authors acknowledged that individuals' epistemic beliefs play a central role in the formation of so-called default stances, advising readers on successful strategies for the comprehension and evaluation of conflicting information sources. Several empirical studies have investigated the abovementioned theoretical assumptions of an association between uncertainty beliefs and the evaluation of scientific controversies. The following section provides an overview of this research.

1.1.4 The role of uncertainty beliefs in the evaluation of scientific controversies

The way individuals think about knowledge and knowing influences how they understand and use science (Conley et al., 2004; Leach, Millar, Ryder, & Séré, 2000; Münchow, Richter, Mühlen, & Schmid, 2019; Nussbaum, Sinatra, & Poliquin, 2008; Sinatra & Chinn, 2012; Yang & Tsai, 2010). According to Sandoval (2005), "sophisticated scientific epistemologies are critical to full democratic participation in the 21st century, as science increasingly pervades aspects of daily life and public policy" (p. 652). Uncertainty beliefs in particular have been shown to correspond with successful learning and achievement (Greene, Cartiff, & Duke, 2018; Muis & Duffy, 2013; Trautwein & Lüdtke, 2007), particularly in the domain of science (Elby, Marcander, & Hammer, 2016; Mason, Boscolo, Tornatora, & Ronconi, 2013; Yang & Tsai, 2012). In line with this reasoning (see also 1.1.3), uncertainty beliefs should play a central role in how individuals understand and evaluate scientific controversies (Bråten et al., 2011; Chinn & Brewer, 1993; King & Kitchener, 2002). Specifically, the literature investigating the influence of uncertainty beliefs on the evaluation of controversial scientific information can be subdivided into three lines of research: research on conflicts within single documents, research on conflicts between multiple documents, and research on source evaluation.

Uncertainty beliefs and the evaluation of controversies within documents

Several studies have investigated individuals' text processing and their conclusions after reading scientific controversies within single documents. Kardash and Howell (2000) investigated the relation between uncertainty beliefs and text processing in a study using think-aloud methodology while participants read a dual-positional text. Results were equivocal: On the one hand, readers with strong uncertainty beliefs made more connections between different parts of the text and drew more inferences. On the other hand, such readers also made more inaccurate statements that indicated that they had misinterpreted the textual information. A study by Richter and Schmid (2010) also focused on the role of uncertainty beliefs in text processing. University students were asked about their reading behavior regarding scientific texts in their own field of study. The authors found that domain-specific uncertainty beliefs were correlated with the use of more advanced consistency checking strategies, especially when extrinsic motivation was low. In a study by Schraw, Dunkle, and Bendixen (1995), participants worked on well-defined tasks that had a single solution and ill-defined tasks that had multiple, tentative solutions. Note that due to their ambiguous and complex nature, scientific controversies can be described as ill-defined tasks (Mason & Scirica, 2006). Results by Schraw et al. (1995) showed that uncertainty beliefs predicted problem solving for ill-defined but not for well-defined tasks. Other studies have used researchers' ratings of participants' written conclusions on controversial texts as a measure of text comprehension. Schommer (1990), for example, had students read passages containing inconsistent theories in two domains (psychology and nutrition) and write a conclusion for each passage. Students adhering to certain knowledge were more likely to write imbalanced and absolute conclusions in both domains. Similarly, Kardash and Scholes (1996) showed that students holding strong uncertainty beliefs wrote more balanced and less one-sided conclusions than did students holding weak uncertainty beliefs after reading a text containing contradictory evidence with respect to a medical issue. The importance of an alignment between a reader's uncertainty beliefs and the amount of uncertainty in a scientific message was demonstrated by Rabinovich and Morton (2012). In a 2x2 experimental design, participants first read different texts about the nature of science. In the first condition, the role of science was described as aiming to find the absolute truth, and in the second condition, the text suggested that science is about debating different versions of the truth. Then, participants read scientific statements that implied either high or low certainty about different possible impacts of climate change. Results showed that participants expressed a higher level of motivation to engage in sustainable behavior such as reducing their water use if the amount of uncertainty in the scientific messages matched the previously read text about the nature of science. That is, those who were induced with strong uncertainty beliefs (debate condition) were more motivated to change their behavior by messages that implied uncertainty, whereas those who were induced with weak uncertainty beliefs (absolute truth condition) were more motivated by messages with high certainty.

Uncertainty beliefs and the evaluation of controversies between documents

The research cited above has been supplemented by studies using a between-documents approach in which readers have to make inferences about a given issue across multiple sources of information (Barzilai & Strømsø, 2018; Bråten, Strømsø, & Ferguson, 2016). Strømsø, Bråten, and Samuelstuen (2008) found that readers with strong uncertainty beliefs scored higher on a test for which they had to draw inferences from multiple documents than readers with weak uncertainty beliefs. Similarly, other studies have shown that readers holding strong uncertainty beliefs outperformed those holding weak uncertainty beliefs when it came to taking on different perspectives after reading different newspaper articles (Schommer-Aikins & Hutter, 2002) or when they were asked to construct arguments on the basis of multiple documents about climate change (Bråten & Strømsø, 2010). Stadtler et al. (2014) found that the advantage of uncertainty beliefs for the construction of arguments after reading multiple conflicting documents depended on the task condition. The authors found that readers holding strong uncertainty beliefs remembered more conflicting information when they were instructed to write a summary after reading several online documents on the topic of cholesterol. However, the advantage of uncertainty beliefs for remembering controversial information could not be shown for other task conditions such as constructing arguments. Gil, Bråten, Vidal-Abarca, and Strømsø (2010) found a different pattern of results regarding the influence of task conditions. In their study, participants were asked to write either a summary (unchallenging task) or an argument essay (challenging task) after reading several controversial documents. Uncertainty beliefs moderated the effect of task condition on multiple text comprehension in the sense that readers with strong uncertainty beliefs showed better comprehension in the argument essay task, whereas weak uncertainty beliefs were associated with better comprehension in the summary task. Moreover, a number of studies investigated the impact of uncertainty beliefs on the evaluation of scientific controversies by analyzing participants' Internet-searching behavior. These studies revealed that readers who believed in certain knowledge conducted brief and perfunctory Web searches (Hofer, 2004b), showed less advanced search strategies (Hsu, Tsai, Hou, & Tsai, 2014), and expressed less need to compare multiple sources (Mason et al., 2010a). Furthermore, readers believing in certain knowledge made less use and were less aware of advanced integration strategies on the Web than were participants with strong uncertainty beliefs (Barzilai & Zohar, 2012), and they accessed fewer websites in a complex learning task (Pieschl, Stahl, & Bromme, 2008).

Uncertainty beliefs and source evaluation

A third line of research that appears relevant in the context of scientific controversies is related to individuals' evaluation of sources. Disagreement between different sources (e.g., experts) usually forms the core of a scientific controversy, and evaluating source features such as expertise and trustworthiness can therefore help to evaluate the respective controversy. Kammerer et al. (2013) demonstrated that uncertainty beliefs—in addition to other epistemic belief dimensions—predicted students' sourcing strategies on the Web, with students who embraced weak uncertainty inspecting the source-relevant areas of the web pages for shorter lengths of time and verbally referring to fewer source features than students with strong uncertainty beliefs. Students' source evaluation was also investigated in the abovementioned study by Barzilai and Zohar (2012). The analysis of students' verbal protocols did not reveal significant differences between participants with strong and weak uncertainty beliefs in terms of evaluation strategies. However, those adhering to certain knowledge as expressed in absolutist views showed less awareness of the potential bias of different source perspectives. In another study, Whitmire (2004) observed that students who believed in certain knowledge preferred information sources that were in line with their own views. On the other hand, students who considered knowledge to be tentative (i.e., those holding strong uncertainty beliefs) in this study judged the trustworthiness of a source by taking into account more valid criteria such as its reputation. Similarly, Barzilai and Eshet-Alkalai (2015) showed that beliefs in certain knowledge as expressed in absolutist views were related to a poorer understanding of different authors' viewpoints.

To sum up, uncertainty beliefs are important for the evaluation of scientific controversies because they advise readers on the cognitive strategies that will help them scrutinize controversial scientific information from single or multiple documents and critically evaluate different sources. Individuals holding strong uncertainty beliefs tend to engage in deep cognitive processing, which enables them to critically and thoroughly balance conflicting knowledge claims about topics they are unfamiliar with. The following section will elaborate on cognitive engagement as a variable that might help individuals put their certainty beliefs into action.

1.2 Engagement

Engagement is a very popular construct in educational research and other related disciplines that is used to describe, among other things, the extents to which individuals commit to learning and enact cognitive resources during tasks (Appleton, Christenson, & Furlong, 2008; Boekaerts, 2016; Finn & Zimmer, 2012). Countless studies have been published in the past few decades that have attempted to measure, explain, or foster student engagement (see Azevedo, 2015). Engagement has been linked to student achievement, persistence, and well-being (e.g., Greene & Miller, 1996; Kuh, Cruce, Shoup, Kinzie, & Gonyea, 2008; Pietarinen, Soini, & Pyhältö, 2014). However, as the scope of the application of the engagement construct increases, its usability decreases, making it a more and more arbitrary term for research (Reschly & Christenson, 2012). Hence, it is necessary to establish a clear theoretical framework regarding the aspects of engagement that are being investigated and the content that engagement is directed toward (Fredricks, Filsecker, & Lawson, 2016). Accordingly, the present dissertation is focused on cognitive engagement in the domain of science. In order to provide an understanding of how to conceptualize this, the following sections first provide a general overview of different engagement dimensions (see 1.2.1), followed by definitional issues regarding cognitive engagement (see 1.2.2) and its role in evaluating scientific controversies (see 1.2.3).

1.2.1 Dimensions of engagement

In their seminal literature overview, Fredricks, Blumenfeld, and Paris (2004) reviewed and structured the existing engagement literature on school and student engagement and identified three different dimensions: behavioral, emotional, and cognitive engagement. Whereas these dimensions are not considered to be distinct, there is a certain level of agreement on what the respective dimensions are comprised of. Behavioral engagement entails participating in learning activities or exerting actions that indicate commitment to a certain task or content area. Emotional engagement is described as individuals' affective reactions or their feeling of belonging with respect to a certain subject, institution, or activity. Finally, cognitive engagement can be regarded as the amount of psychological investment or mental effort that is enacted to solve a given task. Whereas some researchers have postulated additional dimensions such as social engagement (e.g., Wang, Fredricks, Ye, Hofkens, & Linn, 2016), Fredricks et al.'s (2004) classification still appears the most common and most accepted approach to conceptualizing engagement (see Eccles, 2016).

More recently, a handbook and two special issues were introduced with the goal of advancing the engagement construct and contributing to conceptual clarification (Christenson, Reschly, & Wylie, 2012; Fredricks et al., 2016; Sinatra et al., 2015). Among the ambitious goals of these volumes were to establish commonly accepted construct definitions and measurement approaches. However, reviews of the different contributions expressed a lack of satisfaction with them. For example, Eccles (2016) and Reschly and Christenson (2012) concluded that engagement is still a fuzzy construct that is characterized by a multitude of overlapping yet seemingly unique measurement approaches. Furthermore, there is a lack of a theoretically sound foundation of engagement (Azevedo, 2015), which makes it hard to compare findings across different studies that have claimed to measure the same construct. Whereas this broad conceptualization seems to make engagement more easily accessible for policy makers and practitioners, a much more concise approach to the engagement construct is crucial for rigorous research, which can, in turn, inform educational policy and practice (Eccles & Wang, 2012).

It is particularly surprising that there is a shortage of empirical research on engagement in the domain of science (Greene, 2015; Sinatra et al., 2015). The small number of studies dedicated to science engagement is completely disproportionate to the central role that successful science learning plays in the lives of individuals and society (OECD, 2007; Roth & Lee, 2004). Therefore, there is a need for more research on science engagement that has the potential to help students and educators interact with scientific concepts and practices in a meaningful way (Ben-Eliyahu, Moore, Dorph, & Schunn, 2018; McConney, Oliver, Woods-McConney, Schibeci, & Maor, 2014) and possibly to counteract the often observed decline in student engagement that occurs across students' academic careers (Osborne, Simon, & Collins, 2003; Patall, Vasquez, Steingut, Trimble, & Pituch, 2016).

Rather than following the beaten track of comparing cognitive, behavioral, and emotional engagement, this dissertation presents an in-depth analysis of the cognitive engagement dimension in the domain of science. First, from a theoretical point of view, this detailed approach appears much more promising for advancing the understanding of this dimension than could be gained by studying cognitive engagement only on a surface level because it allows for a comparison of different indicators (Azevedo, 2015; Henrie, Halverson, & Graham, 2015). Second, the focus on this dimension was driven by the notion that cognitive engagement is particularly important for formal learning contexts in general and for science in particular (Pintrich & Schrauben, 1992; Sinatra et al., 2015). In line with this, akin to cognitive engagement, the concept of cognitive activation is regarded as a key factor for successful learning (Kunter et al., 2013). Also, particularly when learning complex scientific concepts, individuals must show sufficient cognitive engagement in order to establish new knowledge structures (Pugh, Linnenbrink-Garcia, Koskey, Stewart, & Manzey, 2010; Sinatra et al., 2015).

1.2.2 Toward a definition of cognitive engagement

As can be seen from Fredricks et al.'s (2004) multidimensional approach, there is no clear distinction between different engagement dimensions. Hence, the first step toward a more concise definition of cognitive engagement requires its differentiation from other engagement dimensions. Regarding emotional engagement, there are possible mutual influences with cognitive engagement in the sense that deep cognitive engagement can elicit feelings of enjoyment during learning or, alternatively, that being emotionally engaged in a subject might come along with an increase in the investment of cognitive resources when studying the subject (Pekrun & Linnenbrink-Garcia, 2012; Pietarinen et al., 2014; Wang & Eccles, 2012). Despite these mutual dependencies, the distinction between cognitive engagement and emotional engagement is that the former clearly addresses learning and information processing, whereas the latter can also occur without being directly involved in a certain activity. Moreover, the conceptualizations of cognitive and behavioral engagement show considerable overlap in the literature, and similar or even identical indicators are sometimes used to study cognitive engagement and sometimes used to study behavioral engagement (Appleton et al., 2008; Fredricks et al., 2016). Take for example indicators such as effort or concentration. Whereas these stand for cognitive engagement for some researchers (e.g., Greene, 2015), others have used them to measure behavioral engagement (Schmidt, Rosenberg, & Beymer, 2018; Skinner & Belmont, 1993). Arguably, not all overt and observable behavior is also a valid indicator of behavioral engagement. Rather, certain behaviors such as the time and effort learners invest in reading a text should be seen as a manifestation of their cognitive engagement in a complex task (see also Eccles, 2016).

The second step in defining cognitive engagement requires differentiating it from other constructs that are related but not identical to cognitive engagement. Throughout the literature, two psychological concepts are constantly confounded with cognitive engagement. The first, self-regulated learning, is a concept from cognitive psychology that explains how individuals actively plan, monitor, and evaluate their learning activities (e.g., Pintrich & de Groot, 1990). Some theoretical models of cognitive engagement explicitly incorporate self-regulated learning (Corno & Mandinach, 1983; Pintrich & Schrauben, 1992), and self-regulated learning has been used as a direct indicator of cognitive engagement by empirical studies (Appleton, Christenson, Kim, & Reschly, 2006; Wang & Eccles, 2012). Further, different concepts from the motivation literature have been adapted to assess cognitive engagement, such as students' task values or topic interest (Martin, 2012; Renninger, Ren, & Polman, 2018). Motivation and self-regulation might well play a role in initiating and maintaining cognitive engagement. Motivated learners are likely to be cognitively engaged, and high cognitive engagement is often paired with elaborate self-regulation strategies (Blumenfeld, Kempler, & Krajcik, 2006; Dole & Sinatra, 1998; Singh, Granville, & Dika, 2002; Walker, Greene, & Mansell, 2006; Wolters & Taylor, 2012). However, obliterating the conceptual differences between these constructs is not helpful for explaining reasoning and learning processes. In this sense, "extracting such motivational or self-regulated learning processes, cognitive engagement is cleanly *thinking and paying attention*" (Ben-Eliyahu et al., 2018, p. 88).

The third step toward establishing a definition of cognitive engagement is delineating the boundary conditions in which it takes place. Among these conditions are the domain or topic toward which a person's cognitive engagement is directed, contextual features such as formal or informal learning, and the nature and purpose of the task (Azevedo, 2015; Eccles, 2016). The present dissertation investigates cognitive engagement in a university context, using an evaluation task that contains different scientific topics in a solo setting. Note that variations in these boundary conditions might elicit different forms of cognitive engagement. For example, university students have been shown to differ in their cognitive engagement across different domains (Pintrich & Schrauben, 1992) or when they find themselves in a group setting (Chi & Wylie, 2014). One central boundary condition that has been largely neglected in prior research on cognitive engagement is the level of granularity, that is, the question of whether cognitive engagement is measured on a general or a situational level (Azevedo, 2015; Sinatra et al., 2015). In their research synthesis, Fredricks et al. (2004) already brought up the idea that cognitive engagement "can be short term and situation specific or long term and stable" (p. 61). Subsequent studies, however, have insufficiently explained where they place cognitive engagement on this conceptual space between more general and more situational manifestations. Most of the literature has more or less explicitly focused on general engagement, for example, under the term school engagement (Fredricks et al., 2004). The latter end of the continuum, situational engagement, has been investigated with reference to different settings or tasks (Lau & Roeser, 2002; Lee & Anderson, 1993). Moreover, individuals can be more or less aware of their situational engagement (Eccles, 2016). This implies that the observed cognitive engagement of individuals in a given situation might differ from their self-reported cognitive engagement. What is still missing are studies that focus on general and situational aspects as well as explicit and implicit aspects of cognitive engagement in order to clarify the conceptual relations between these manifestations within the cognitive engagement construct (Wang & Degol, 2014). These distinctions have important implications for operationalizing, measuring, and eventually fostering cognitive engagement.

In summary, in the present dissertation, cognitive engagement is defined as individuals' general or situational effortful allocation of mental resources, with higher levels of cognitive engagement indicating deeper processing of information in a certain task (see also Alongi et al., 2016; Aubteen Darabi, Nelson, & Paas, 2007; Greene, 2015; Miller, 2015). Thus, this approach distinguishes cognitive engagement from other engagement dimensions (behavioral and emotional engagement) and related constructs (self-regulated learning and motivation). However, given the complexity of learning and reasoning processes, an overlap between cognitive engagement and other engagement dimensions as well as related constructs has to be assumed.

This definition also implies that different measurement approaches are needed to capture different manifestations of cognitive engagement. Whereas in educational research, different self-report scales have been introduced to capture general cognitive engagement (Greene, 2015), the cognitive load literature, specifically research on mental effort, has informed engagement research with measures of situational cognitive engagement (Hyönä, Tommola, & Alaja, 2007; Kalyuga, 2011; Kirschner, Kester, & Corbalan, 2011; Korbach, Brünken, & Park, 2017; Paas, 1992). Note that even though they hail from different research traditions, the concepts of situational cognitive engagement and mental effort have very similar implications. Much like cognitive engagement, cognitive load theory states that mental effort refers to the cognitive resources allocated by a learner in order to solve a task (Kalyuga, 2011; Paas, Tuovinen, Tabbers, & van Gerven, 2003; Paas, Tuovinen, van Merriënboer, & Aubteen Darabi, 2005). More specifically, mental effort is expressed by germane cognitive load, whereas extraneous cognitive load is imposed by instructional factors, and intrinsic cognitive load refers to load imposed by the task. Hence, when learners are cognitively engaged, their germane load, and thereby their mental effort, is maximized, while extraneous load is reduced (Ayres & Paas, 2012; Kirschner et al., 2011). Connecting both approaches, Greene (2015) proposed that mental effort is a situational component of cognitive engagement. Furthermore, measures of cognitive engagement include effort as an indicator of psychological learning investment (e.g., Wang et al., 2016). The present dissertation combines situational measures established by cognitive load research with self-report data as used in research on student engagement. In doing so, it adds to prior research by triangulating different data sources in order to draw a more detailed picture of cognitive engagement, with respect to both general and situational aspects (see also Fredricks & McColskey, 2012; Salmela-Aro, Moeller, Schneider, Spicer, & Lavonen, 2016).

1.2.3 The role of cognitive engagement in the evaluation of scientific controversies

Compared with the epistemic beliefs literature, research addressing the role of cognitive engagement for the evaluation of scientific controversies is less abundant. This results from the fact that the already scarce research on science engagement has conceptualized cognitive engagement inconsistently, exacerbating the problem of studies that are difficult to compare. To date, there is no overarching theoretical framework linking the evaluation of scientific controversies to cognitive engagement. One step that was taken in this direction can be found in the cognitive-affective engagement model of multiple source use by List and Alexander (2017). The authors identified four different profiles established by crossing two dimensions: affective engagement (e.g., individuals' interest) and behavioral dispositions (e.g., individuals' sourcing skills). The four resulting profiles are thus (a) disengaged (low affective engagement; low behavioral dispositions), (b) affectively engaged (high affective engagement; low behavioral dispositions), (c) evaluative (low affective engagement; high behavioral dispositions), and (d) critical analytic (high affective engagement; high behavioral dispositions). With regard to the scope of the present dissertation, particularly the evaluative and critical analytic profiles appear relevant for the evaluation of scientific controversies. Students with these profiles are hypothesized to compare multiple information sources (evaluative profile) and engage in the evaluation and integration of these sources (critical analytic profile; List & Alexander, 2017). However, whereas the List and Alexander (2017) model intertwines different engagement dimensions, it does not allow for a targeted analysis of cognitive engagement in and of itself.

Several studies have empirically investigated cognitive engagement in science. Even though the focus of these studies was not explicitly to evaluate scientific controversies, they exemplify characteristic aspects of it. In a recent study by Bråten, Brante, and Strømsø (2018), students were presented with multiple texts about controversial scientific issues in two conditions: climate change and nuclear power. Students were asked to select from among these texts the ones that they would include when writing a letter to the editor. The authors measured students' time, effort, and persistence and referred to these indicators as behavioral engagement. This illustrates the conceptual confusion that is peculiar to the engagement literature. As argued earlier, even though measures such as time, effort, and persistence might come along with behaviorally observable indicators, they are still consistent with the definition of cognitive engagement as effortful mental involvement. In line with this reasoning, the results of this study suggested that cognitive engagement can explain a number of student outcomes, including the number of texts selected, students' justification for their selection, and the length of their written products. For example, the amount of time students spent reading the chosen documents was associated with the number of information units they included from these texts when writing the letter to the editor, even after reading comprehension ability, topic knowledge, and interest were controlled for.

Similarly, Bråten, Anmarkrud, Brandmo, and Strømsø (2014) had students read different texts on the risks of sun exposure, and the authors measured "effort" (i.e., cognitive engagement) as the total reading time for these texts. Results from path analyses showed that students with high cognitive engagement were more eager to compare and integrate information across different texts, and they showed better understanding of the multiple texts than students with low cognitive engagement as revealed by an essay task.

Schmidt et al. (2018) analyzed high school science students' engagement during different classroom activities using the experience sampling method, in which participants were prompted to complete a self-report measure by a vibrating pager at random points during the lesson. One of the engagement profiles revealed by cluster analysis was referred to as "rational". This profile, in which cognitive engagement was high and behavioral and emotional engagement were low, became particularly apparent during activities such as laboratory work and formal assessment. Both of these contexts required students to interpret and question scientific data, actions that are also central for the evaluation of scientific controversies. On the other hand, the "rational" profile was found less frequently during activities such as engaging in individual work or listening to a lecture. Note that behavioral engagement in this study was operationalized with indicators such as concentration. Again, this would more aptly describe cognitive engagement (see also Ben-Eliyahu et al., 2018). Presumably, profiles with high cognitive engagement would have been even more influential in the study by Schmidt et al. (2018) if concentration had been included as part of the cognitive dimension.

Rotgans and Schmidt (2011) investigated university science students' self-reported situational cognitive engagement during different phases of a problem-based learning task. For this task, students first needed to identify a given scientific problem and work on it individually. Then, they discussed their findings, first within their own small group and later between different small groups. Results showed that students' situational cognitive engagement increased when they started discussing their findings with others, indicating that being exposed to diverging viewpoints can elicit cognitive engagement. Further, cognitive engagement at all measurement points was positively correlated with student achievement.

Finally, Smart and Marshall (2013) observed middle school science classrooms over the course of 1 school year and measured both teachers' behavior and students' cognitive engagement. Results revealed that cognitive engagement in students was associated, among other things, with the complexity of questions asked by the teacher. Whereas questions targeting a single correct answer were related to low cognitive engagement in students, questions focusing on evidence and reasoning came along with high cognitive engagement. Further, classroom interactions in which students discussed their ideas prompted more cognitive engagement than when the teacher explained the right answer.

Taken together, these studies suggest that cognitive engagement is associated with the central elements that are necessary for evaluating scientific controversies, such as paying attention to different sources and complex problem solving.

1.3 Integrating Uncertainty Beliefs and Cognitive Engagement

In the previous sections, it was demonstrated that both uncertainty beliefs and cognitive engagement should play critical roles in the evaluation of scientific controversies. The largest impact on the conceptualization of epistemic beliefs and cognitive engagement came from two literature reviews by Hofer and Pintrich (1997) and Fredricks et al. (2004). In what followed, researchers further expanded these constructs using a multitude of study designs for a variety of applications. In order to integrate those two multifaceted research traditions into an overarching framework, it is crucial to identify the conceptual similarities between them. Only then will it be possible to develop research designs that can account for the characteristics of both epistemic belief and engagement research. However, a comparison of these two constructs is not trivial because the respective literatures vary significantly in coherence. On the one hand, epistemic belief researchers have taken efforts to exchange and integrate their ideas through symposia or shared publications. The same cannot be said for engagement research, which is still characterized by fragmentation rather than synergy (Boekaerts, 2016). Therefore, the present dissertation focuses on the critical issues that most cognitive engagement researchers agree on and that are in line with the definition of cognitive engagement as effortful mental processing.

1.3.1 Conceptual commonalities between uncertainty beliefs and cognitive engagement

The first conceptual commonality between uncertainty beliefs and cognitive engagement is that both variables are influenced by the characteristics of the task in which they unfold. In particular, the goals with which individuals approach a task can range from learning-oriented goals where they focus on mere understanding to performance-oriented goals including summarizing, evaluating, and discussing the information they are provided with. Prior research has shown that different task definitions or goal orientations can impact both uncertainty beliefs (Bråten & Strømsø, 2010; Chen, 2012; Pieschl, Stallmann, & Bromme, 2014; Wiley, Jaeger, & Griffin, 2018) and cognitive engagement (Greene & Miller, 1996; Meece, Blumenfeld, & Hoyle, 1988; Miller et al., 2014). As a result, research aimed at integrating these two constructs should always provide a detailed description of the tasks that are being employed as well as the goals that reflect how the task has to be solved.

Second, when investigating the influences of uncertainty beliefs and cognitive engagement on evaluations of conflicting scientific knowledge claims, individual differences in reading comprehension ability have to be accounted for (Cho, Woodward, & Li, 2018; Guthrie & Wigfield, 1998; Guthrie, Wigfield, & You, 2012; Miller, 2015). When individuals examine different knowledge claims in a text, the question is whether they do so in accordance with their uncertainty beliefs or as a consequence of poor reading skills. Similarly, it is important to differentiate between whether individuals invest effort in a reading task simply due to the fact that they are not proficient readers (i.e., they are trying to understand the information) or because they are cognitively engaged (i.e., they aim to deeply process the material beyond merely understanding it, see also Miller et al., 2014).

A third major issue common to both uncertainty beliefs and cognitive engagement is related to domain specificity. A large body of theoretical and empirical work has addressed the question of whether uncertainty beliefs (and other epistemic belief dimensions) are domain-general or domain-specific (e.g., Limón, 2006) or even topic-specific (Kardash & Howell, 2000; Strømsø et al., 2008). According to Buehl and Alexander (2006), domain-specific beliefs are informed by general beliefs. Similarly, in their theory of integrated domains in epistemology (TIDE), Muis, Bendixen, and Haerle (2006; see also Muis, Trevors, Duffy, Ranellucci, & Foy, 2015) proposed a set of interrelated domain-specific beliefs that are partly based on more general beliefs. The authors also introduced a temporal dimension, in the sense that both general and specific epistemic beliefs develop over time. The TIDE implies that domain-general and domain-specific epistemic beliefs are interrelated but that the latter are also shaped by characteristics of the context and the respective domain. Recently, Merk, Rosman, Muis, Kelava, and Bohl (2018) investigated the predictions of the TIDE by comparing general and specific aspects of student teachers' absolute (i.e., certain) and multiplistic (i.e., uncertain) beliefs in two studies. In both cases, the authors found evidence for a reciprocal influence between general and specific beliefs. In line with the assumptions of the TIDE, other studies have shown not only that individuals' uncertainty beliefs influence their choice of study but also that their domain of study shapes their uncertainty beliefs over the course of their academic careers (Hofer, 2004a; Trautwein & Lüdtke, 2008). By contrast, Aditomo (2017) investigated the relation between college students' achievement and their uncertainty beliefs and found no differences regarding students' domains. A look into cognitive engagement research also shows a differentiation between domain-general and domain-specific aspects (Fredricks et al., 2004; Green, Martin, & Marsh, 2007). Even though the latter is still underrepresented in the literature, some studies have investigated cognitive engagement in science on a domain level (Lee & Anderson, 1993) or cognitive engagement during science-related activities (Ben-Eliyahu et al., 2018; Rotgans & Schmidt, 2011). However, comparisons between broad and specific conceptualizations of cognitive engagement in science are still missing. Similar to the abovementioned defining features of cognitive engagement, this question refers to general versus situational manifestations of the construct.

From a broader perspective, the question of the domain-generality versus the domain-specificity of uncertainty beliefs and cognitive engagement is related to the stability of these constructs. When talking about uncertainty beliefs and cognitive engagement, should they be referred to as traits, states, or both? Presumably, trait-like manifestations of the measured constructs will be more relevant for domain-general aspects, and state-like manifestations will be more relevant for domain-specific aspects. This question has important implications for both theorizing about and measuring these constructs. The present dissertation is aimed at capturing trait-like and state-like aspects of uncertainty beliefs and cognitive engagement, thus advancing the understanding of how these different manifestations are interrelated in a science context.

In terms of measurement, trait-like or stable and general aspects are usually assessed with so-called offline measures, whereas state-like or situational aspects are measured with online data (Schraw, 2010). Offline measures are usually administered outside the context of a specific task, whereas online measures are assessed during task performance. Among these offline measures, self-report instruments in which individuals agree or disagree usually with general aspects of the respective constructs have been developed and validated (DeBacker, Crowson, Beesley, Thoma, & Hestevold, 2008; Greene, 2015; Henrie et al., 2015; Mason, 2016). Following a domain-specific approach, science-related measures of uncertainty beliefs (Conley et al., 2004) and cognitive engagement (Wang et al., 2016) have been introduced. Even though these instruments focus on a specific knowledge domain, they can still be considered general rather than situation-specific because they refer to typical behavior and general aspects of science. On the other hand, online measures have been used to assess state-like or situational aspects of the respective constructs. For example, individuals' enacted uncertainty beliefs during a task have been investigated with verbal reports and eye-tracking technology (Ferguson et al., 2012; Mason et al., 2010a; Trevors, Feyzi-Behnagh, Azevedo, & Bouchet, 2016). Situational cognitive engagement has also been assessed with eye tracking (Marshall, 2005; Miller, 2015) as well as with a single-item self-report measure that can be administered repeatedly during a task (Paas, 1992). Prior research has been criticized for relying too much on a single measure or for not using appropriate measures when assessing either trait or state-like aspects of uncertainty beliefs and cognitive engagement (Azevedo, 2015; Mason, 2016). Following a "right tool for the right job" perspective (Sandoval et al., 2016, p. 483), the present dissertation addresses this issue by clearly defining which aspects of the respective constructs are being measured and choosing well-established and appropriate measures accordingly (see also Bromme et al., 2010; Fredricks & McColskey, 2012). Table 1.2 provides an overview of the nomenclature and the respective measurement approaches regarding the trait- and state-like aspects of uncertainty beliefs and cognitive engagement used in the present dissertation.

Table 1.2

Conceptualization and assessment of uncertainty beliefs and cognitive engagement in the present dissertation

	Uncertainty beliefs		**Cognitive engagement**	
	trait	state	trait	state
Nomenclature	professed uncertainty beliefs	enacted uncertainty beliefs	general cognitive engagement	situational cognitive engagement / mental effort
Measurement approach	offline (questionnaire)	online (eye tracking, verbal reports)	offline (questionnaire)	offline (self-report) and online (eye tracking)

1.3.2 Theoretical and empirical links between uncertainty beliefs and cognitive engagement

The present dissertation builds on the assumption that uncertainty beliefs and cognitive engagement have a meaningful connection in the same conceptual space. Even though this assumption has hardly been empirically investigated before, it has been substantiated by numerous theoretical accounts in the literature. Several authors have speculated about an interrelation between uncertainty beliefs and cognitive engagement (e.g., Kuhn, 2005; Sinatra, 2016). Moreover, different theoretical frameworks have established links between epistemic beliefs and engagement in the context of evaluating contradictory information.

Theoretical links between uncertainty beliefs and cognitive engagement

In their integrative personal epistemology model, Bendixen and Rule (2004) specified how a person’s current beliefs can translate into more advanced beliefs through a mechanism of change. This mechanism is initiated when certain conditions are met, such as being confronted with contradictory information. The components of the model’s change mechanism include a state of epistemic doubt in which a person’s prior beliefs are challenged, leading to increased volition to challenge those beliefs and ultimately in the use of resolution strategies such as deliberate reflection. These change components, in turn, are influenced by metacognition, which Bendixen and Rule (2004) defined as being “on a continuum of engagement, from low to high” (p. 74). In this sense, high engagement would facilitate the development of epistemic beliefs by focusing on appropriate strategies for evaluating conflicting information.

Stadtler and Bromme (2014) introduced the content-source integration model in which they distinguish three different stages of how readers understand conflicting scientific information: conflict detection, conflict regulation, and conflict resolution. Whether readers detect a conflict in Stage 1 is influenced by individual factors such as cognitive capacity as well as task factors such as reading goals. In Stage 2, conflict regulation, readers can either ignore, accept, or reconcile conflicting knowledge claims. Stadtler and Bromme (2014) suggested that uncertainty beliefs play a role in reconciling conflicts, with beliefs in certain and unambiguous knowledge making it hard for readers to establish a coherent mental representation of the conflict. Finally, in Stage 3, readers can resolve conflicts by engaging in either first-hand evaluation (e.g., drawing on prior knowledge) or second-hand evaluation (e.g., estimating a source’s expertise). As discussed in the Introduction of this dissertation, second-hand evaluation of conflicting knowledge claims is the rule rather than the exception (see also Bromme et al., 2013). Although not explicitly stated in the model by Stadtler and Bromme (2014), cognitive engagement in the sense of effortful mental processing plays a central role in all three stages when readers evaluate conflicting information. Engaged readers are more likely to detect conflicts in texts and dedicate more cognitive resources to their regulation and resolution (see also Alongi et al., 2016).

Richter and Maier (2017) also provided a theoretical model to explain how readers understand and evaluate conflicting information, specifying two steps during which individuals evaluate belief-inconsistent information. Step 1 refers to nonstrategic validation, and Step 2 refers to the strategic elaboration of inconsistencies in texts. Both steps involve certain conditions, processes, and outcomes. In Step 1, readers’ prior beliefs are the condition for the process of monitoring and detecting text-belief inconstancies. One potential outcome lies in a belief-biased representation of the controversy. However, when readers detect information that is inconsistent with their prior beliefs, they can also proceed to Step 2 and engage in the effortful elaboration of this information. This elaboration can result in a balanced representation of the controversy. Besides factors such as working memory capacity and background knowledge, readers’ epistemic beliefs are also among the conditions behind this elaboration process. Regarding uncertainty beliefs, Richter and Maier (2017) proposed that readers holding the belief that “knowledge is certain and never changing (as opposed to fallible and changing) will see no point in resolving conflicts between their beliefs and text information and in constructing a balanced mental model of controversial issues” (p. 152). As in the aforementioned model by Stadtler and Bromme (2014), Richter and Maier (2017) also did not explicitly introduce the term cognitive engagement. However, the authors repeatedly referred to the importance of engaging in elaborative processing, and many of the studies they reviewed for their model measured the allocation of cognitive resources to investigate readers' detection of text-belief inconsistencies, which is well in line with the way cognitive engagement is defined in the present dissertation. One implication of the model by Richter and Maier (2017) is that readers' uncertainty beliefs should affect the manner in which they process and evaluate a scientific controversy containing contradictory knowledge claims and that an effortful elaboration of the information they encounter (i.e., cognitive engagement) can help them develop a more advanced mental representation of the controversy.

Which conceptual relation between uncertainty beliefs and cognitive engagement is assumed by the three models that have been presented? Despite different assumptions about the cognitive processes readers apply when evaluating scientific controversies, all the models imply a process in which epistemic beliefs guide readers' cognitive engagement (see also Hogan, 2000). In this regard, uncertainty beliefs could be described as a structural component or an underlying mindset, whereas cognitive engagement represents a more procedural component of evaluation processes, facilitating the enactment of uncertainty beliefs.

Empirical links between uncertainty beliefs and cognitive engagement

One of the few examples of an empirical investigation of the relation between uncertainty beliefs and cognitive engagement came from Ravindran, Greene, and DeBacker (2005). The authors put together two scales from different self-report measures to assess preservice teachers' deep and shallow cognitive engagement, respectively. Results showed a correlation between uncertainty beliefs and shallow cognitive engagement, in the sense that believing in certain knowledge came along with more shallow processing strategies. No correlation between uncertainty beliefs and deep cognitive engagement was found. Similarly, DeBacker and Crowson (2006) investigated the relations between epistemic beliefs, goal orientations, and deep and shallow cognitive engagement in university students. Because uncertainty beliefs were combined with other epistemic belief dimensions into a single scale, the results did not allow for a detailed analysis. The authors found that students who held "naïve" beliefs also had lower mastery goal orientations, indicating they attributed failure to a lack of ability rather than a lack of effort. In turn, students' mastery goals were positively correlated with both deep and shallow cognitive engagement. In another empirical investigation of the relation between uncertainty beliefs, cognitive engagement, and goal orientations, Rastegar et al. (2010) ran a path analysis using correlational data collected from university science students. Results revealed that students’ goal orientations mediated the relation between uncertainty beliefs and cognitive engagement, which was measured using two questionnaire scales on cognitive and metacognitive strategies. To be precise, those with weak uncertainty beliefs (i.e., those who believed that knowledge is certain) also had higher performance avoidance goals and lower mastery goals. Performance avoidance goals, in turn, were related to the increased use of cognitive strategies, whereas mastery goals were related to the increased use of metacognitive strategies. Notably, the cognitive engagement measures in most of these studies were related more to self-regulated learning strategies than to effortful processing, making it hard to compare these previous findings with the conceptual orientation adopted by the present dissertation. Nonetheless, these studies provide preliminary support for the assumption that uncertainty beliefs can elicit cognitive engagement. Furthermore, two studies by Yang, Huang, and Tsai (2016) and Scheiter, Gerjets, Vollmann, and Catrambone (2009) investigated the relation between uncertainty beliefs and mental effort, which can be regarded as an indicator of situational cognitive engagement, as outlined above. Using an eye-tracking approach, Yang et al. (2016) used the average fixation duration on selected parts of a text about a study on global warming as an indicator of mental effort. The authors found that readers with strong uncertainty beliefs displayed less mental effort when reading the part of the text that contained a scientific explanation. Yang et al. (2016) interpreted this finding to mean that participants holding strong uncertainty beliefs found the respective passage easier to read. Scheiter et al. (2009), on the other hand, found no correlation between uncertainty beliefs and mental effort as indicated by participants’ subjective ratings after a hypermedia task.

1.4 Research Questions in the Present Dissertation

The aim of the present dissertation is to investigate the role of university students' uncertainty beliefs and cognitive engagement in the evaluation of scientific controversies. Besides examining the interplay of these constructs, this dissertation adds to prior research by providing a detailed investigation of different facets of uncertainty beliefs and cognitive engagement, respectively. In doing so, it combines different research traditions such as educational science and cognitive psychology, and it pursues an innovative methodological approach by triangulating online and offline data. As the present dissertation provides an integrated view of uncertainty beliefs and cognitive engagement as well as in-depth analyses of the two constructs, it contributes to both a broader and a deeper conceptual understanding, providing insights into how the beliefs students hold and the engagement they invest operate in the context of scientific controversies. From a broader perspective, the present dissertation investigates factors that can expand the understanding of how individuals in our modern-day knowledge society evaluate conflicting scientific information.

The focus of the present dissertation on the domain of science was driven by the notion that successful learning, knowledge, and reasoning in this domain influence individuals' personal, vocational, and political decisions (Goldman & Scardamalia, 2013; Sandoval, 2005; Sinatra & Hofer, 2016). In this regard, both students' uncertainty beliefs (Duschl, 2008; Kirch, 2012; Sandoval, 2005) and their cognitive engagement (Corno & Mandinach, 1983; National Research Council, 2012) play key roles in science education. The focus on the evaluation of controversies in the domain of science, in turn, was informed by several research traditions that have used contradictory information as a means for studying learning and reasoning in science. First, the present dissertation is compatible with the science education literature in using scientific controversies as a framework from which to study and foster students' understanding of science (Hess, 2009; Sadler & Dawson, 2012). Second, the present dissertation connects to conceptual change research and more specifically to the refutation text paradigm in which readers are confronted with contradictions and inconsistencies in texts in order to initiate learning (Sinatra & Broughton, 2011; Tippett, 2010). Third, research on multiple documents literacy has demonstrated the fruitfulness of having students compare conflicting viewpoints in order to study their understanding of scientific information (Bråten et al., 2016; Bråten & Braasch, 2018). Using scientific controversies as a framework is particularly promising in the present dissertation because not only have scientific controversies been assumed to elicit engagement (Anmarkrud, Bråten, & Strømsø, 2014), but they have also been used as a breeding ground for the manifestation and development of epistemic beliefs (Britt & Rouet, 2012; Kienhues et al., 2016).

1.4.1 Overview of the studies conducted in the context of the present dissertation

In total, three studies were conducted to answer three respective research questions:

(1) *How are uncertainty beliefs and cognitive engagement interrelated when university students evaluate scientific controversies?*

(2) *How are different indicators of cognitive engagement related to the evaluation of scientific controversies?*

(3) *How are different indicators of uncertainty beliefs related to the evaluation of scientific controversies?*

The first research question addresses the overarching conceptual relation between uncertainty beliefs and cognitive engagement; the second research question provides an in-depth investigation of cognitive engagement; and the third research question involves a detailed analysis of uncertainty beliefs.

Concerning the first research question, Study 1 (*The Role of Beliefs Regarding the Uncertainty of Knowledge and Mental Effort as Indicated by Pupil Dilation in Evaluating Scientific Controversies*) investigated the interplay of uncertainty beliefs and cognitive engagement during the evaluation of scientific controversies. Specifically, in Study 1, it was predicted that both strong uncertainty beliefs and high cognitive engagement would be associated with university students' proficient evaluation of scientific controversies. Moreover, the relation between uncertainty beliefs and evaluation was expected to be at least partly mediated by cognitive engagement. These hypotheses were informed by prior research, which suggested that evaluating contradictory knowledge claims is affected by individuals' uncertainty beliefs (Bråten et al., 2011; Schraw et al., 1995) as well as their cognitive engagement (Bråten, Brante et al., 2018; Smart & Marshall, 2013). Moreover, the theoretical accounts discussed earlier imply that uncertainty beliefs serve as a prerequisite for the investment of cognitive engagement in a given context (e.g., Bendixen & Rule, 2004; Kuhn, 2005; Sinatra, 2016). The mediation analysis in Study 1 was an empirical investigation of this hypothesis. In this regard, Study 1 followed calls for more theoretical clarification regarding epistemic beliefs and other related constructs such as cognitive engagement as well as mediational analyses to clarify how these constructs are interrelated (Bråten et al., 2011; Hofer, 2016). To test these expectations, a sample of $N = 44$ undergraduate university students was recruited from an online database. Participants first completed an online questionnaire in which their uncertainty beliefs were assessed. One week later, they worked on a standardized test in which they had to evaluate five textual controversies pertaining to different scientific issues. During this controversy-evaluation test, participants' pupil dilation (i.e., their pupil diameter during test taking relative to a baseline measure) was recorded using a remote eye tracker. Note that by using this pupil dilation measure, situational cognitive engagement in Study 1 was conceptualized as mental effort. Uncertainty beliefs referred to students' professed beliefs as measured with a self-report scale.

Concerning the second research question, Study 2 (*Different Indicators of Cognitive Engagement and Their Relation to Evaluating Scientific Controversies*) investigated the interrelations of different indicators of cognitive engagement as well as their roles in evaluating of scientific controversies. In line with theoretical assumptions and prior research, cognitive engagement can manifest on a general as well as on a situational level (Fredricks et al., 2004; Salmela-Aro et al., 2016). Furthermore, individuals can be more or less aware of their situational engagement, which is why self-reported and process-related measures of cognitive engagement have been introduced (Paas, 1992; van der Wel & van Steenbergen, 2018). Study 2 provided detailed comparisons of these different manifestations of cognitive engagement in the domain of science. Specifically, the following research questions were investigated. First, the interrelations of the different cognitive engagement measures were explored. Second, the relations between these measures and other related constructs, such as science interest and reading comprehension ability, were assessed. Third, Study 2 investigated how the different cognitive engagement measures were related to students' performance on the abovementioned controversy-evaluation test. These research questions addressed pending questions in the literature. Despite the multitude of studies on cognitive engagement, an empirical comparison of general and situational manifestations of cognitive engagement was still missing. Furthermore, prior research has often confounded or even confused cognitive engagement with other related constructs (Renninger et al., 2018; Reschly & Christenson, 2012). By assessing different indicators of cognitive engagement and related constructs separately, Study 2 contributes to more theoretical clarification. Moreover, as Greene (2015) pointed out in her review, the consequences of cognitive engagement have seldom been investigated. That is, little is known about how cognitive engagement affects learning processes and outcomes, particularly in the domain of science (Sinatra et al., 2015). Study 2 was aimed at filling this research gap by investigating the relations between different cognitive engagement measures and students' performance on the controversy-evaluation test. Participants in Study 2 were N = 40 university science students from different majors. General cognitive engagement was measured via self-report in a preceding questionnaire. Situational cognitive engagement was measured in a lab session while participants worked on the controversy-evaluation test. Specifically, self-reported situational cognitive engagement was measured repeatedly during the controversy-evaluation test with a single-item self-report scale, and process-related situational cognitive engagement was measured with different fixation time measures as well as pupil dilation, using the same procedure as in Study 1.

Finally, concerning the third research question, Study 3 (*Investigating Professed and Enacted Epistemic Beliefs About the Uncertainty of Knowledge When Students Evaluate Scientific Controversies*) investigated the relation between professed and enacted uncertainty beliefs. More specifically, the research questions in Study 3 concerned the interrelations of professed uncertainty beliefs, enacted uncertainty beliefs, and the evaluation of scientific controversies. Moreover, the assumption of an enactment of underlying beliefs in a particular context was tested with a mediation analysis, that is, the question of whether professed uncertainty beliefs would influence evaluation through enacted uncertainty beliefs. Even though, more or less explicitly, a distinction between professed and enacted epistemic beliefs has often been drawn in the literature (see Table 1.1), it is still unclear how these different conceptualizations are related (Alexander, 2016; Mason, 2016). The enacted aspect of epistemic beliefs, which has been referred to as epistemic cognition (Greene et al., 2016a), was assumed by some authors to be determined by context, regardless of a stable set of beliefs (e.g., Elby & Hammer, 2010). Others have argued that rather than favoring one conceptualization over the other, research should dig into the theoretical and methodological connections between epistemic beliefs and epistemic cognition (Hofer, 2016; Kienhues et al., 2016). In line with this reasoning, in Study 3, both professed and enacted uncertainty beliefs were assessed and compared. For Study 3, data from Studies 1 and 2 were combined, with a resulting sample of N = 79. Professed uncertainty beliefs were measured with the same self-report scale used in Study 1. Enacted uncertainty beliefs were measured with a verbalization technique in which participants retrospectively reported what they thought about while they were working on the aforementioned controversy-evaluation test. Their verbalizations were guided by playing back a recording of their own eye movements, which served as a cue. The resulting verbal protocols of these so-called cued retrospective reports (van Gog, Paas, van Merriënboer, & Witte, 2005) were coded with regard to participants' uncertainty beliefs, that is, whether participants' utterances referred to the tentative and evolving nature of knowledge. Table 1.3 provides a summarizing overview of the titles, goals, research questions, and samples of the three studies.

Table 1.3

Overview of the three studies conducted in the context of the present dissertation

Study	*Study goal*	*Research questions*	*Sample and materials*
Study 1 *The Role of Beliefs Regarding the Uncertainty of Knowledge and Mental Effort as Indicated by Pupil Dilation in Evaluating Scientific Controversies*	Investigating the respective influences of uncertainty beliefs and cognitive engagement on the evaluation of scientific controversies as well as the interplay of uncertainty beliefs and mental effort.	1) Is there a positive relation between uncertainty beliefs and evaluation? 2) Is there a positive relation between uncertainty beliefs and cognitive engagement? 3) Is there a positive relation between cognitive engagement and evaluation? 4) Is the relation between uncertainty beliefs and evaluation mediated by cognitive engagement?	*Sample:* *N* = 44 university students *Materials:* uncertainty beliefs questionnaire, pupil dilation measure (indicator of cognitive engagement / mental effort measured by eye tracking), controversy-evaluation test, control variables (reading comprehension ability, science interest, science self-concept, conscientiousness, several eye-tracking measures)
Study 2 *Different Indicators of Cognitive Engagement and Their Relation to Evaluating Scientific Controversies*	Exploring the interrelations of different cognitive engagement indicators as well as their roles in the evaluation of scientific controversies.	1) How are different indicators of general and situational cognitive engagement related? 2) What are the relations between different cognitive engagement indicators and related variables? Are there unique associations between (a) general cognitive engagement and motivational variables and (b) situational cognitive engagement and reading comprehension ability? 3) What are the relations between different cognitive engagement indicators and evaluation?	*Sample:* *N* = 40 university students *Materials:* general cognitive engagement (questionnaire), self-reported situational cognitive engagement (self-report), process-related situational cognitive engagement (pupil dilation, fixation time measures), controversy-evaluation test, control variables (reading comprehension ability, science interest)
Study 3 *Investigating Professed and Enacted Epistemic Beliefs About the Uncertainty of Knowledge When Students Evaluate Scientific Controversies*	Investigating the respective influences of professed and enacted uncertainty beliefs on the evaluation of scientific controversies as well as the interplay of professed and enacted uncertainty beliefs.	1) Is there a positive relation between professed and enacted uncertainty beliefs? 2) Is there a positive relation between professed uncertainty beliefs and evaluation? 3) Is there a positive relation between enacted uncertainty beliefs and evaluation? 4) Is the relation between professed uncertainty beliefs and evaluation mediated by enacted uncertainty beliefs?	*Sample:* *N* = 79 university students *Materials:* uncertainty beliefs questionnaire (professed uncertainty beliefs), cued retrospective reports (enacted uncertainty beliefs), controversy-evaluation test, control variables (reading comprehension ability, different eye-tracking measures)

1.4.2 Theoretical and methodological connections between the studies

Several similarities between the individual studies can be identified, and these hint at the bigger picture of how the present dissertation addresses overarching questions and gaps in prior research. First, all three studies used the same controversy-evaluation test as an outcome variable, providing common ground for the interpretation of how participants evaluated scientific controversies in the context of the present dissertation. Given the context-bound nature of both cognitive engagement and uncertainty beliefs, a detailed description of contextual features has to be provided, in terms of both the contents of the study materials and the ways in which they were administered. According to Bromme et al. (2010), “the analysis of beliefs, planning, and acting of the learner has to be complemented by an analysis of the learning content in order to assess the functionality of the first mentioned for coping with the latter” (p. 23; see also Fredricks et al., 2016). Therefore, in the following paragraphs, the rationale behind the controversy-evaluation test as well as the way it was administered in the three studies will be explained in detail. The controversy-evaluation test was originally developed by Kramer, Oschatz, Wagner, Thomm, and Bromme (2019) in the context of the National Education Panel Study (NEPS; see also Oschatz, Kramer, & Wagner, 2017). It was based on the concept of metascientific reflection, which includes the juxtaposition and integration of inconsistent or contradictory scientific assumptions (Huber, 1997; Müsche, 2009). The controversy-evaluation test consists of five vignettes, each comprising a scientific controversy. Each of these controversies entails a short introduction, followed by the conflicting positions of two fictitious scientists on a scientific issue. Each controversy is accompanied by five to seven items, containing claims regarding central aspects of the respective controversy. These claims refer to underlying causes of the controversies, which can be based on theoretical, methodological, or ethical aspects of science, and they have to be rated as correct or incorrect by participants. Hence, the controversy-evaluation test does not require participants to have any prior knowledge about the scientific controversies. Rather, high test scores indicate proficient evaluation in the sense that participants are able to identify plausible underlying causes of the scientific controversies (cf. Thomm et al., 2015). In all the studies included in the present dissertation, the controversy-evaluation test was administered on a computer screen in a solo setting. The five controversies next to the corresponding items were presented in successive order, and participants were not able to switch back and forth between the controversies. Participants’ eye movements and pupil diameter during test processing were recorded with a remote eye tracker, and their head position was fixed with a chin rest. Items were answered via mouse click. In all the studies, the controversy-evaluation test took up the first part of each lab session, followed by the assessment of control variables such as reading comprehension ability. In Study 3, the verbalization procedure (cued retrospective reports), which was based on the playback of the recordings of the eye movements, was conducted directly after the controversy-evaluation test was completed. Figure 1.2 illustrates the setup that was used. Superimposed on the computer screen is a so-called area of interest (AOI) that was defined after data collection to analyze the eye-tracking data from selected parts of the test, as well as a dot that was used during the collection of the cued retrospective reports in Study 3.

The second common feature was that all three studies investigated university students. The focus on this sample was motivated by the fact that the central theoretical constructs in the present dissertation (i.e., uncertainty beliefs and cognitive engagement) as well as the context of the studies (i.e., scientific controversies) are highly relevant for this target group. Opposing theoretical viewpoints or contradictory empirical evidence are typical across different academic

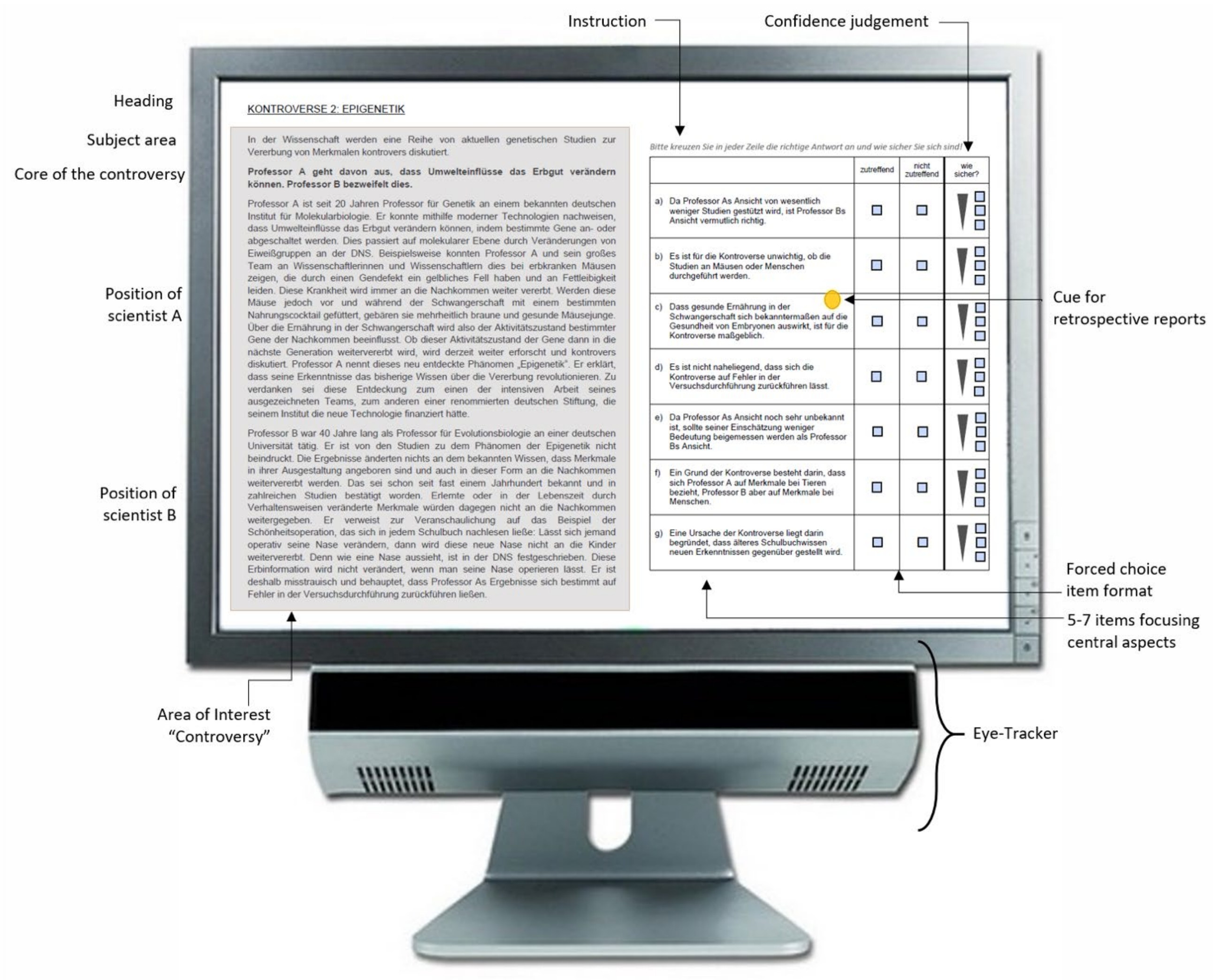

Figure 1.2 *Sample controversy as shown to study participants on a computer screen*

disciplines (Sadler & Dawson, 2012; Sandoval, 2016; Tabak, 2018). Moreover, both uncertainty beliefs and cognitive engagement have been shown to affect university students' achievement (Greene & Miller, 1996; Muis & Duffy, 2013). University students are not only confronted with competing knowledge claims in their academic lives. In this age group, when individuals want to make decisions that require science-related information, they predominantly search the Web where they have to deal with multiple, potentially contradictory information sources (Alexander, 2012; Strømsø & Kammerer, 2016). Hence, the present dissertation addresses a population for which evaluating scientific controversies is important for both their academic and their personal lives (OECD, 2007; Sinatra & Hofer, 2016).

Third, the studies controlled for potential confounding variables that have been associated in prior research with the dependent measure used in the present dissertation (evaluating scientific controversies) as well as the respective independent measures (uncertainty beliefs and cognitive engagement). For example, reading comprehension ability has been linked to individuals' ability to evaluate contradictory scientific information (Britt et al., 2014) as well as their epistemic beliefs (Kendeou, Muis, & Fulton, 2011) and cognitive engagement (Bråten, Brante et al., 2018; Miller, 2015). Hence, in all three studies, a reading comprehension measure was used to increase the interpretability of the results. Among other control variables that were used in at least two of the three studies is participants' science-related interest. Controlling for this variable provided a way to clarify whether participants' uncertainty beliefs and cognitive engagement influenced the ways in which they evaluated scientific controversies regardless of their interest.

Finally, the synopsis of the three studies documents a progression from a broad analysis of the interplay of uncertainty beliefs and cognitive engagement using a single indicator for each construct (Study 1) to using detailed analyses involving multiple indicators of cognitive engagement (Study 2) and uncertainty beliefs (Study 3). Whereas Study 1 investigated the interplay of professed uncertainty beliefs and situational cognitive engagement, Studies 2 and 3 provided in-depth analyses relating to trait-like and state-like aspects of the measured constructs (see Table 1.2). Trait-like aspects are conceptualized as professed uncertainty beliefs and general cognitive engagement, and state-like aspects are conceptualized as professed uncertainty beliefs and situational cognitive engagement. The underlying assumption is that individuals' general cognitive engagement corresponds to situational cognitive engagement in a given context (Study 2) and that professed uncertainty beliefs become manifest in enacted uncertainty beliefs (Study 3). These different manifestations of uncertainty beliefs (professed and enacted) and cognitive engagement (general and situational) are expected to operate within the same conceptual space, rather than being fundamentally different. Bearing this in mind, contextual demands were expected only to affect the shape of the more general constructs but not to alter the nature of it, which is why small to moderate correlations between state- and trait-like aspects were expected. As for epistemic beliefs, Kienhues et al. (2016) expected that “in similar contexts, similar elements will contribute to epistemic cognition” (p. 326). In other words, when investigating different operationalizations of uncertainty beliefs and cognitive engagement, trait-like variables should at least to some extent translate into state-like variables in contexts in which they are adaptive (see also Appleton et al., 2008; Bromme et al., 2010). The present dissertation introduces the evaluation of scientific controversies as a context that is highly relevant for the measured constructs as well as for learning, reasoning, and achievement in general (Alongi et al., 2016; Bromme, Stadtler, & Scharrer, 2018; Greene & Yu, 2016)

2

Study 1

The Role of Beliefs Regarding the Uncertainty of Knowledge and Mental Effort as Indicated by Pupil Dilation in Evaluating Scientific Controversies

Lang, F., Kammerer, Y., Oschatz, K., Stürmer, K., & Gerjets, P.

Abstract

Laypeople are increasingly confronted with scientific controversies, as science concerns many aspects of everyday life. In the present study, we investigated how epistemic beliefs regarding the uncertainty of knowledge (i.e., uncertainty beliefs) and invested mental effort during task processing contribute to how individuals evaluate scientific controversies. Forty-four undergraduate university students completed a questionnaire targeting their uncertainty beliefs and a week later worked on a test that required the evaluation of five scientific controversies. Eye-tracking technology was used to measure participants' pupil dilation while reading the controversies, as an indicator of individuals' invested mental effort. Results revealed that both uncertainty beliefs and mental effort were positive predictors of individuals' test performance (i.e., their proficient evaluation of the controversies). Furthermore, uncertainty beliefs predicted mental effort. Finally, a mediation analysis revealed that mental effort partially explained the relation between uncertainty beliefs and test performance. We discuss implications of how individuals' epistemic beliefs regarding the uncertainty of knowledge influence the evaluation of conflicting scientific information through mental effort, offering both theoretical clarification and practical recommendations.

Keywords: epistemic beliefs; beliefs regarding the uncertainty of knowledge; mental effort; scientific controversies; pupil dilation

Introduction

Is genetically modified food harmful? Will my child become more aggressive after playing video games? Scientific controversies like these are a pervasive phenomenon in today's knowledge society (Sinatra, Kienhues, & Hofer, 2014). With scientific knowledge being broadly accessible via modern media, laypeople are often confronted with inconsistent or even contradictory knowledge claims on scientific issues held by different sources (Goldman & Scardamalia, 2013; Greene & Yu, 2016). Therefore, the ability to evaluate scientific controversies is crucial for laypeople as it ensures informed decisions and democratic participation (Carey & Smith, 1993; Kuhn, 2005; Sinatra et al., 2014). However, it is not possible for laypeople to know and understand all relevant scientific findings of any given subject. They must therefore develop the competence to weigh and evaluate the contradictory knowledge claims they encounter (Bromme & Goldman, 2014; Herring, 1918). Specifically, key to evaluating a scientific controversy is the ability to detect and interpret its underlying causes (Britt, Richter, & Rouet, 2014). However, research has just begun to discover factors that positively relate to individuals' competent evaluation of scientific controversies.

One key factor that is likely to predict how individuals evaluate scientific problems are their epistemic beliefs as subjective theories about knowledge and knowing (Thomm, Hentschke, & Bromme, 2015). The advancement of epistemic beliefs in the domain of science have been shown to be related to learning scientific concepts and practices (Bråten & Ferguson, 2014; Elby, Marcander, & Hammer, 2016). Specifically, beliefs regarding the certainty or uncertainty of knowledge, a core component of epistemic beliefs (Trautwein & Lüdtke, 2007), have the potential to influence how individuals evaluate competing scientific knowledge claims (Bråten, Britt, Strømsø, & Rouet, 2011). Beliefs regarding the certainty or uncertainty of knowledge range from views that knowledge is certain, that is, absolute and unchanging, to views that knowledge is uncertain, that is, tentative and evolving (Hofer, 2004; Hofer & Pintrich, 1997). As will be outlined below, previous research indicates that beliefs that knowledge is uncertain (hereafter referred to as uncertainty beliefs) are beneficial for the evaluation of scientific controversies (e.g., Barzilai & Zohar, 2012; Kardash & Scholes, 1996). Yet what are the mechanisms of how individuals' uncertainty beliefs lead to a more critical evaluation of scientific issues? In the present paper, we aimed to examine the role of mental effort (i.e., deep cognitive processing) while evaluating scientific controversies as a potential mediator of the relationship between individuals' uncertainty beliefs and evaluation performance. It has been assumed that epistemic beliefs should be positively related to individuals' invested mental effort during task processing, especially in the context of evaluating contradictory claims (Kuhn, 2005; Sinatra, 2016). However, respective mediational mechanisms have been seldom considered in previous research (cf. Bråten et al., 2011). One exception is a study by Richter and Schmid (2010), who found that beliefs in uncertain knowledge were positively related to readers' monitoring of text consistency, with this relationship being mediated by epistemic curiosity, that is, a motivational state that is assumed to arise from facing uncertain knowledge. In the present study, we aimed to pursue an innovative approach in the realm of epistemic beliefs research by triangulating eye-tracking measures and traditional questionnaire data to examine the relation between uncertainty beliefs and the evaluation of scientific controversies, as well as the mediating role of mental effort. In order to examine individuals' evaluation of scientific controversies, we used a set of different controversial scientific topics, allowing for more generalizable conclusions than when using only a single controversial issue (cf. Bråten et al., 2011). In the following, we review prior research on uncertainty beliefs and mental effort in the context of reading and evaluating conflicting scientific information.

The role of uncertainty beliefs in the evaluation of scientific controversies

Individuals differ in how certain, or uncertain, they consider knowledge to be. These beliefs pertaining to the certainty or uncertainty of knowledge serve as a knowledge structure that influences to a great degree how new information is integrated and evaluated (Britt, Rouet, & Braasch, 2013). From a broader perspective, beliefs regarding the certainty or uncertainty of knowledge constitute one dimension of individuals' epistemic beliefs, that is, their personal views about knowledge and the process of knowing (Hofer & Pintrich, 1997). This belief dimension can be described on a continuum ranging from views that knowledge is certain (i.e., absolute and unchanging) to views that knowledge is uncertain (i.e., tentative and evolving, Hofer & Pintrich, 1997). Moreover, key to this dimension is whether individuals believe that there is always one "right answer", or whether they recognise that there may be conflicting and even contradictory knowledge claims that can be more or less valid depending on criteria such as the validity of explanations or the quality of arguments (Britt et al., 2014). Since scientific controversies provide a context of inherent tentativeness (Britt & Rouet, 2012), it seems reasonable that when evaluating such controversies individuals will strongly benefit from viewing knowledge as uncertain. Beliefs toward the latter end of the continuum should therefore be beneficial for a competent evaluation of controversial scientific information.

In this vein, Bråten et al. (2011) proposed a theoretical framework of the role of different epistemic belief dimensions for understanding multiple, conflicting information sources. The authors suggest that readers who believe that knowledge is uncertain might be more apt to juxtapose and integrate inconsistent information sources of a given issue, whereas readers who believe that knowledge is certain might perceive their task to be to identify the information source that provides the correct answer (Bråten et al., 2011). Accordingly, readers who believe that knowledge is certain will likely process the provided information superficially, whereas readers who believe that knowledge is uncertain might engage in more in-depth processing.

Several previous studies provide evidence for the above-mentioned assumption linking uncertainty beliefs to the evaluation of scientific controversies (Barzilai & Zohar, 2012; Bråten & Strømsø, 2010; Kardash & Scholes, 1996; Kendeou, Muis, & Fulton, 2011; Mason, Gava, & Boldrin, 2008; Schommer, 1990; Strømsø, Bråten, & Samuelstuen, 2008; Thomm, Barzilai, & Bromme, 2017). In task conditions where readers were confronted with multiple and partly conflicting documents on a scientific issue, those adhering to uncertain knowledge were at an advantage when it came to constructing arguments (Bråten & Strømsø, 2010), drawing inferences (Strømsø et al., 2008), and using advanced integration strategies (Barzilai & Zohar, 2012). Similar results have been shown when readers had to deal with conflicts or inconsistencies within a single document. Readers who believed that knowledge is uncertain performed better when solving ill-defined problems that hold multiple, tentative solutions (Rukavina & Daneman, 1996; Schraw, Dunkle, & Bendixen, 1995). On the other hand, individuals who believed that knowledge is certain tended to write more imbalanced and one-sided conclusions after being confronted with inconsistent information (Kardash & Scholes, 1996; Schommer, 1990).

The above-mentioned findings are also corroborated by studies that measured individuals' ongoing cognitive processes while they were confronted with scientific issues (Hofer, 2004; Hsu, Tsai, Hou, & Tsai, 2014; Kendeou et al., 2011; Mason et al., 2008; Mason, Boldrin, & Ariasi, 2010; Pieschl, Stahl, & Bromme, 2008). For example, using think-aloud methodology, Kendeou et al. (2011) showed that readers who believed that knowledge is uncertain also engaged in more advanced conceptual change processes when reading refutational text. Hofer (2004) examined students' Internet search behaviours and found that those who believed that knowledge is certain conducted brief and perfunctory searches. In a study by Hsu et al. (2014), participants performed a Web search on a socioscientific issue while the screen was being recorded. Results showed that students who believed in uncertain knowledge (in addition to other epistemic belief dimensions) outperformed those believing in certain knowledge regarding online searching strategies. Similarly, Mason et al. (2010) had participants complete a Web search task on a scientific issue. Participants who regarded the issue as more uncertain in retrospective interviews saw a greater need to compare multiple sources in contrast to participants who regarded the issue as certain, and they based their arguments on scientific evidence rather than the expertise of a resource. Logfile analyses by Pieschl et al. (2008), who had students read a hierarchical hypertext on genetic fingerprinting, revealed that the more students held beliefs in uncertain knowledge, the more pages they accessed during learning. These findings imply that readers adhering to uncertain knowledge delve deeper into the learning material, even if the information is ambiguous and contradictory. A positive effect of uncertainty beliefs on performance in general was also reported in a recent meta-analysis by Greene, Cartiff, and Duke (2018).

In sum, the research mentioned above indicates that uncertainty beliefs are important for the evaluation of scientific controversies, as they prompt individuals to use cognitive strategies that help them scrutinise and contrast controversial scientific information from single or multiple sources instead of briefly searching for a single correct answer. Paragraph: use this for the first paragraph in a section, or to continue after an extract.

The role of mental effort

Most of the above-mentioned findings showed, more or less explicitly, a relationship between individuals' uncertainty beliefs and depth of processing or the invested mental effort, respectively, when working on a complex task (e.g., Hofer, 2004; Pieschl et al., 2008). This is in line with theoretical assumptions made by Hofer and Pintrich (1997), who suggested that epistemic beliefs may influence individuals' motivational approach in conducting certain tasks. Similarly, Sinatra (2016) expected that a person's willingness to think deeply should be related to more availing epistemic cognition. Kuhn (2005, p. 32) argued that for individuals adhering to certain knowledge "there is little point to expending the mental effort that the evaluation of claims entails" (see also DeBacker & Crowson, 2006). This evaluation, which requires the juxtaposition and integration of contradictory knowledge claims, imposes high demands on a reader's cognitive resources (Rouet, 2006). These resources, in turn, should be more likely to be actuated if the reader is equipped with a mindset that acknowledges contradictions and inconsistencies in science (Gill, Ashton, & Algina, 2004; Muis, 2007). Accordingly, we propose that a reader believing that knowledge is uncertain will likely invest more mental effort, that is, engage in deeper information processing, in the epistemically challenging task of evaluating scientific controversies (cf. Ravindran, Greene, & DeBacker, 2005). Following a definition by Paas, Tuovinen, van Merriënboer, and Aubteen Darabi (2005), the enactment of mental effort is a voluntary process that depends on an individual's available resources in relation to task demands. In other words, "mental effort is the feature that distinguishes between mindless or shallow processing on the one hand, and mindful or deep processing, on the other" (Salomon, 1983, p. 44). Given that task difficulty is not too high, an increase in mental effort in the sense of deeper processing usually comes along with higher achievement (Aubteen Darabi, Nelson, & Paas, 2007; Paas et al., 2005; Paas & van Merriënboer, 1993).

To the best of our knowledge, only two studies explicitly related individuals' uncertainty beliefs to mental effort. In an eye-tracking study by Yang, Huang, and Tsai (2016), fixation time measures were used as an indicator for mental effort. The authors presented participants with a scientific paper on global warming. Correlational analyses between fixation time measures and different segments of the reading material did not reveal a systematic relationship between uncertainty beliefs and mental effort. In a study by Scheiter, Gerjets, Vollmann, and Catrambone (2009), participants navigated through a hypermedia task on probability theory, and mental effort was measured by participants' subjective ratings subsequent to the learning task. Results did not reveal any relationship between participants' uncertainty beliefs and mental effort.

In sum, mental effort has seldom been considered in prior research on uncertainty beliefs, and existing conceptualizations and measures are inconsistent as they draw on different approaches to capture mental effort. The lack of empirical findings in the above-mentioned studies by Yang et al. (2016) and Scheiter et al. (2009) might be due to this lack of suitable measurements for mental effort. Particularly, subjective and retrospective ratings of mental effort (Scheiter et al., 2009) might not adequately capture mental effort in real-time while individuals are working on a certain task (Brünken, Plass, & Leutner, 2003; Naismith, Cheung, Ringsted, & Cavalcanti, 2015). One line of research that offers a more promising approach to capturing mental effort during task processing refers to individuals' pupil dilation whilst working on a task as an indicator of mental effort. It has been shown that the pupil becomes larger when individuals are confronted with cognitively challenging tasks, providing evidence that the autonomic pupil response can be used as a marker of mental effort (Beatty, 1982; Hyönä, Tommola, & Alaja, 2007; Korbach, Brünken, & Park, 2017; Krejtz, Duchowski, Niedzielska, Biele, & Krejtz, 2018; Kühl, Stebner, Navratil, Fehringer, & Münzer, 2018; Scharinger, Kammerer, & Gerjets, 2015; van der Wel & van Steenbergen, 2018). Pupil dilation has also been shown to correspond with achievement measures when learning from pictures (Kühl et al., 2018), or during a visual search task (Porter, Troscianko, & Gilchrist, 2007). Using eye-tracking technology, it is possible to precisely capture pupil dilation, resulting in a real-time measure of mental effort during task processing. Compared to retrospective self-reports, this measure of mental effort has the added value of providing more spontaneous and unbiased responses (Korbach et al., 2017; van Gog & Paas, 2008).

The present study

The aim of the present study was to investigate the role of uncertainty beliefs in the evaluation of scientific controversies and how this relationship might be mediated by individuals' mental effort invested during task processing. We used eye-tracking technology to gain an online measure of how deeply individuals process information (Grant & Spivey, 2003; Lindner et al., 2014; Scheiter & van Gog, 2009), thus revealing precise insights into readers' mental effort (Piquado, Isaacowitz, & Wingfield, 2010; van der Wel & van Steenbergen, 2018; van Gerven, Paas, van Merriënboer, & Schmidt, 2004). Moreover, we combined our mental effort measure with traditional offline measures (i.e., individuals' task achievement and their self-reported uncertainty beliefs). In doing so, we sought to fill gaps in prior research by using a comprehensive theoretical framework and methodological implementation of those measures. While prior research has mainly focused on a single controversial issue (e.g., Lombardi, Seyranian, & Sinatra, 2013), in the present study we cover a range of scientific controversies in order to increase generalizability of our results. We chose to examine undergraduate university students in the present study because in this age group it becomes increasingly important to evaluate conflicting scientific claims in order to make decisions both in their academic and personal life (Goldman & Scardamalia, 2013). At the same time, being in the early phase of their studies, socialization effects due to the epistemologies of their respective fields of study are less likely to affect our results (Trautwein & Lüdtke, 2008). Specifically, we tested the following four hypotheses:

First, building on the assumptions by Bråten et al. (2011) on the relationship between uncertainty beliefs and the processing of conflicting knowledge claims, we predicted that beliefs in uncertain knowledge would be positively related to a competent evaluation of scientific controversies, indicated by the identification of plausible causes underlying the controversies (Hypothesis 1).

Second, we hypothesised that beliefs in uncertain knowledge would be positively related to the amount of mental effort invested while evaluating scientific controversies (Hypothesis 2).

Third, we expected that the amount of mental effort invested would be positively related to a competent evaluation of scientific controversies (Hypothesis 3), in line with past research linking mental effort to performance in complex reading tasks (Kupiainen, Vainikainen, Marjanen, & Hautamäki, 2014; Paas et al., 2005; Paas & van Merriënboer, 1993).

Finally, we investigated whether the assumed positive association between uncertainty beliefs and performance in evaluating scientific controversies is explained by the degree of mental effort invested. Specifically, as a logical extension of our previous assumptions, we hypothesised that the relation between uncertainty beliefs and performance would be mediated by mental effort (Hypothesis 4). To the best of our knowledge, this assumption has never been tested in prior research.

Method

Participants

The sample consisted of 44 undergraduate university students (38 female, 6 male) from different majors (21 from social sciences, 8 from natural sciences and medicine, 8 from business and economics, 7 from psychology) at a large German university. German was the first language of all participants. Their mean age was 20.3 years (*SD* = 1.13), and they received 12 Euros for their participation. All participants had normal or corrected-to-normal vision.

Materials

Controversy-evaluation test. The dependent measure of the present study was students' performance in evaluating scientific controversies. This was measured with a controversy-evaluation test that requires the critical evaluation of five texts, each describing a scientific controversy between two scientists and respective claims regarding central aspects of the controversy (Kramer, Oschatz, Wagner, Thomm, & Bromme, 2019). The controversy-evaluation test was initially developed for high-school students of grades 12 and 13 in the context of the National Education Panel Study (NEPS; Oschatz, Kramer, & Wagner, 2017). Each of the five texts comprises a vignette describing a scientific controversy regarding an actual scientific debate. Table 2.1 provides an overview over the titles, content, and length of the five scientific controversies. As can be seen from the titles, the controversy-evaluation test covers a range of different topics within the domain of science. Each of the controversies is presented on one page (*M* = 349.6 words, *SD* = 52.68), containing a short introduction into the topic followed by a description of the opposing perspectives of two fictitious scientists on the respective issue. Five to seven items containing a statement about possible reasons for the controversy or the conflicting claims, respectively, are presented on the right-hand side of the controversial text (see Figure 2.1). These statements need to be judged as correct or incorrect. In total, the controversy-evaluation test consists of 32 dichotomous items and shows an acceptable reliability of α = .70 based on the present study.

Table 2.1

Description of the scientific controversies of the controversy-evaluation test

Title of the controversy	*Content*	*Number of words*	*Number of items*
Nervous dogs	Two scientists argue whether nervousness of dogs is best treated with behavioural training or medication.	369	5
Epigenetics	Two scientists argue whether or not environmental influences can change the DNA.	376	7
Marathon training	Two scientists argue about the effectiveness of a marathon training,	273	6
Chemical plant	Two scientists argue whether or not the emissions of a chemical plant are harmful.	309	7
Preimplantation Diagnostics	Two scientists argue about scientific and ethical aspects of genetic testing prior to implanting embryos.	410	7

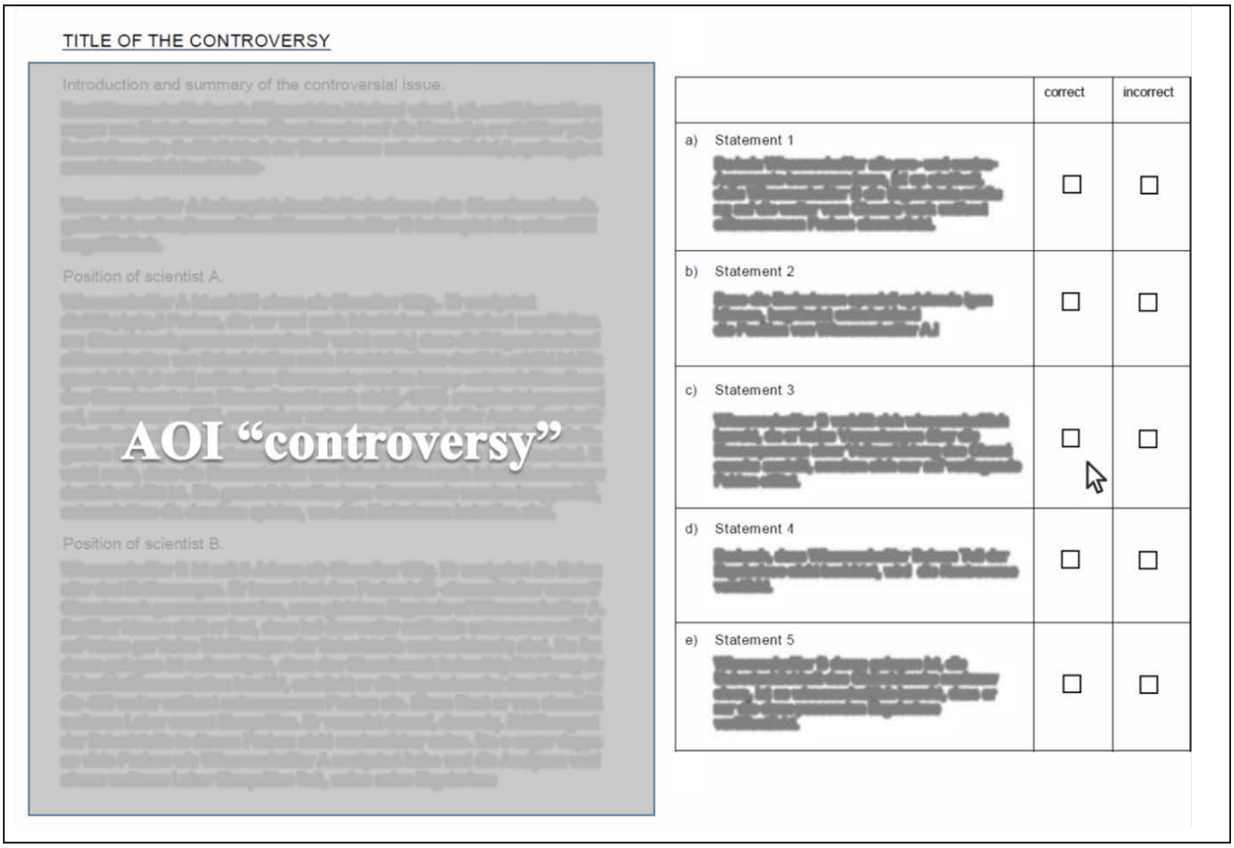

Figure 2.1 *Schematic illustration of a controversy from the controversy-evaluation test with the AOI (area of interest) superimposed*

The items were carefully designed such that they can be solved by interested laypeople. They do not require topic knowledge within the particular discipline, nor do they address mere text comprehension. Rather, readers are required to make inferences about possible causes for the controversy through critical reflection. For high test scores, readers need to infer plausible causes that relate to inherent aspects of the controversies, such as the justification of theoretical assumptions made by the opposing scientists or the validity of the respective measurement approaches. In the following, this rationale is illustrated by two sample items from the controversy “Chemical plant”.

In the respective controversy, two chemists present soil samples from varying distances to a chemical plant, resulting in contradictory claims as to whether the emissions were harmful. One of the chemists stresses that children playing close to the chemical plant would be in particular danger. One item relating to this controversy is “The argumentation of Scientist A would also be plausible if he didn’t refer to playing children.” For a correct answer, participants need to recognise that, in this case, a reference to playing children does not convey a valid argumentation by itself. Therefore, the right answer to this item is “correct”, and readers need to identify that the underlying cause of the controversy lays in different interpretations of the presented data rather than in a reference to playing children. Another item addressing this controversy is “Because scientist B wants to demonstrate the harmlessness of the chemical plant, it is scientifically correct that he publishes only the matching results”. Here, participants need to identify the underlying cause that the collection and presentation of scientific data should not be determined by desired results. Therefore, the right answer to this item is “incorrect”.

Uncertainty beliefs. To assess participants’ beliefs regarding the uncertainty of knowledge in the domain of science, we used two subscales of the Scientific Epistemological Beliefs Questionnaire developed by Conley, Pintrich, Vekiri, and Harrison (2004). These subscales are labelled certainty of knowledge (6 items, e.g. “Scientists always agree about what is true in science.”) and development of knowledge (6 items, e.g. “Ideas in science sometimes change.”), with the combination of these scales corresponding well to the aforementioned conceptualization of uncertainty beliefs by Hofer and Pintrich (1997; cf. Mason et al., 2008). Items from the certainty subscale were recoded so that high values for all items indicate beliefs in uncertain knowledge. The resulting scale consisted of 12 items that were answered on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree), with an acceptable reliability of $\alpha = .75$.

Mental effort. We used eye-tracking technology to measure participants’ mental effort while working on each of the scientific controversies of the evaluation test. For this purpose, we defined an area of interest (AOI) for each controversy covering the complete controversial text, adding up to five AOIs in total. Then, we analysed participants' pupil dilation regarding those AOIs. To eliminate distorting influences on pupil dilation, lighting conditions were held constant and screen distance was fixed using a chinrest. In order to control for interindividual differences in pupil size, before working on a controversy, participants fixated a neutral stimulus (the validation stimulus from the SMI ExperimentCenter software, i.e., four small black dots that were presented sequentially), providing a baseline measure of their pupil diameter (Beatty & Lucero-Wagoner, 2000; Hyönä et al., 2007). Pupil diameter during baseline was recorded separately for each controversy to increase measurement accuracy. This baseline was then subtracted from participants' averaged pupil diameter when working on a controversy, resulting in a measure for task-evoked pupillary response for each of the five controversies (Beatty, 1982; Krejtz et al., 2018). Finally, we averaged this measure across all controversies.

Control variables. As potential control variables we assessed individuals' reading comprehension ability, investigative interest, science self-concept, and conscientiousness. *Reading comprehension ability* was measured with a standardised German reading comprehension cloze test (Schneider, Schlagmüller, & Ennemoser, 2007), with a score ranging from -23 to +46. In a preceding online questionnaire, we assessed *investigative interest* with 10 items on a 5-point Likert-scale (Bergmann & Eder, 2005), *science self-concept* with 9 items on a 4-point Likert-scale (Köller, Watermann, Trautwein, & Lüdtke, 2004), and *conscientiousness* with 12 items on a 5-point Likert-scale (Borkenau & Ostendorf, 2008).

Because we used eye-tracking to measure mental effort, as additional control variables we were able to compute further eye-tracking measures that in previous research have been shown to correspond with processing inconsistent information (Hyönä, Lorch, & Rinck, 2003). Specifically, we computed participants' *total fixation duration* (i.e. the total time they processed a controversy), their *average fixation duration* (i.e., the mean duration of a single fixation while reading a controversy), as well as the *number of fixations* while reading a controversy. Furthermore, we assessed participants' *test taking time* for each controversy, that is, the overall time they spent on the controversy-evaluation test (including the time taken to respond to the items). No specific hypotheses were formulated regarding these control variables. To facilitate interpretation, we averaged those measures across all five controversies, so that they represent participants mean values per trial.

Apparatus

To record participants' eye movements, a remote eye-tracking system with 250 Hz by SMI SensoMotoric Instruments using infrared cameras positioned below a 22-inch Dell monitor set to a resolution of 1,680 x 1,050 pixels was used. A chin rest was used to avoid head movements during data recording and to guarantee a fixed distance of about 70 cm between the eyes and the eye-tracking device. Fixations (and saccades) were detected with the saccade velocity detection algorithm from the default settings of the SMI BeGaze 3.5 software used for data processing.

Procedure

First, to assess participants' uncertainty beliefs and demographics, we administered an online questionnaire that they could access from home. The second phase of the study took place in a research lab approximately one week after completion of the online questionnaire. Participants were tested in single sessions. They completed the controversy-evaluation test on a computer screen while their eye-movements were recorded with a remote eye-tracker. Each controversy of the test was presented successively as a single trial on the screen with a maximum time of 6 minutes per controversy. The accompanying items were presented simultaneously to the right of the controversy and were answered via mouse click (see Figure 2.1). The procedure of using a standardised test as a stimulus for eye-tracking allowed us to simultaneously obtain both meaningful test scores and measures of cognitive processes during test-taking (cf. Lindner et al., 2014). Before each of the five trials, participants were calibrated on the eye-tracking system using a nine-point calibration, and their baseline pupil diameter was recorded. After completion of the controversy-evaluation test, reading comprehension ability was assessed.

Data preparation

Pupil dilation measures were computed and aggregated over all five AOIs that covered the scientific controversies. In four cases of poor calibration, the respective trial was excluded from the analysis to improve data quality. Aggregation was then conducted for the remaining trials. We tested our hypotheses by conducting correlational, multiple linear regression, and mediation analyses. Note that we report standardised values for all multivariate analyses to allow for easier interpretation.

Results

Descriptive results as well as zero-order correlations for the controversy-evaluation score, uncertainty beliefs, mental effort, and control variables are reported in Table 2.2. Regarding the controversy-evaluation test, average test-taking time per controversy was 217.42 seconds (SD = 43.86), and participants answered M = 23.68 (SD = 4.02) items out of 32 correctly.

There were negative correlations between reading comprehension ability and total fixation duration (r = -.35, p = .019) and average fixation duration (r = -.33, p = .028), respectively, and a positive correlation between investigative interest and science self-concept (r = .67, p < .001). However, none of the control variables (variables 4 to 11 in Table 2.2) was significantly correlated with the controversy-evaluation score, uncertainty beliefs, or mental effort (all *p*s > .10). Consequently, we did not account for these control variables in the remaining analyses.

Hypotheses 1, 2, and 3: Uncertainty beliefs, controversy-evaluation score, and mental effort

With Hypothesis 1, we predicted that uncertainty beliefs would be positively related to students' performance in the controversy-evaluation test. As can be seen from Table 2.2, there is a strong positive correlation between uncertainty beliefs and participants' controversy-evaluation score (r = .61, p < .001; Cohen, 1988), indicating that the more participants adhered to uncertain knowledge, the better was their performance on the controversy-evaluation test, supporting Hypothesis 1.

Second, we hypothesised that uncertainty beliefs would be positively related to mental effort. As shown in Table 2.2, in line with Hypothesis 2 uncertainty beliefs and pupil dilation were significantly correlated (r = .30, p = .049), indicating that the more participants adhered to uncertain knowledge, the more mental effort they invested in processing the controversies.

Hypothesis 3 predicted that mental effort would be positively associated with evaluation performance. As can be seen from Table 2.2, there was a strong positive association between pupil dilation and participants' controversy-evaluation score (r = .41, p = .005), indicating that the more mental effort participants invested in reading the controversies, the better was their performance on the controversy-evaluation test, supporting Hypothesis 3.

Hypothesis 4: The mediating role of mental effort

Hypothesis 4 assumed that the relationship between uncertainty beliefs and the controversy-evaluation score is mediated by mental effort. Following the classic work of Baron and Kenny (1986), establishing a mediation requires four steps. (1) The causal variable affects the outcome variable (path *c*); (2) the causal variable affects the mediator (path *a*); (3) the

Table 2.2

Intercorrelation matrix and descriptive statistics

Variable	1	2	3	4	5	6	7	8	9	10	*M*	*SD*	*min*	*max*	*Skewness*	*Kurtosis*
1. Controversy-evaluation score	—										23.68	4.02	15	32	-0.22	-0.62
2. Uncertainty beliefs	.61***	—									4.42	0.33	3.75	4.92	-0.38	-1.01
3. Mental effort (pupil dilation)	.41**	.30*	—								0.02	0.10	-0.24	0.24	-0.24	0.10
4. Reading comprehension ability	.13	.22	.00	—							20.36	7.39	1	40	0.09	1.18
5. Investigative interest	.02	.04	.07	.06	—						3.12	0.70	1.40	4.50	0.00	-0.21
6. Science self-concept	.08	.05	.25	-.12	.67***	—					2.66	0.62	1.44	4.00	0.17	-0.65
7. Conscientiousness	-.10	-.12	-.20	-.16	.11	.17	—				3.65	0.48	2.08	4.42	-0.93	1.34
8. Total fixation duration in sec.	.08	.01	.07	-.35*	.24	.10	.08	—			97.13	21.73	53.91	146.86	0.14	-0.52
9. Average fixation duration in ms	-.16	-.21	-.08	-.33*	.10	.07	-.02	.52***	—		244.94	26.60	183.31	301.87	-0.10	-0.34
10. Number of fixations per controversy	.18	.14	.14	-.24	.19	.07	.09	.87***	.04	—	397.03	77.62	249.40	572.40	0.32	-0.30
11. Test-taking time per controversy in sec.	-.03	-.01	.06	-.25	.13	.04	.16	.85***	.32*	.84*	217.42	43.86	125.16	311.76	0.15	-0.39

Note. $N = 44$. Descriptive statistics for variables 8 to 11 represent averaged values per controversy of the evaluation test.
*$p < .05$, **$p < .01$, ***$p < .001$

mediator affects the outcome variable when the causal variable is controlled for (path *b*); (4) when controlling for the mediator, the effect of the causal variable on the outcome variable vanishes (complete mediation) or becomes smaller (partial mediation; path *c'*). As can be derived from the previous analyses, the requirements of Steps 1 to 3 were met for mental effort. To test whether there is a significant mediation effect for mental effort as specified in Step 4, we applied the Process template developed by Hayes (2013). This bootstrapping-based procedure allows for significance testing when looking at the indirect effect. Analyses were set to 10,000 bootstraps. The mediation model with mental effort as mediator of the effect uncertainty beliefs on the controversy-evaluation score is shown in Figure 2.2. Although the relation between uncertainty beliefs and the controversy-evaluation score did not disappear when including the mediator mental effort (path c': $\beta = .53$, $SE = .12$, $p < .001$), we found evidence for a significant indirect effect as indicated by the bootstrapping analysis and the resulting confidence intervals, $a*b = .08$ (CI 95% [0.008, 0.203]). That is, the relation between uncertainty beliefs and controversy-evaluation score was partly mediated by mental effort.

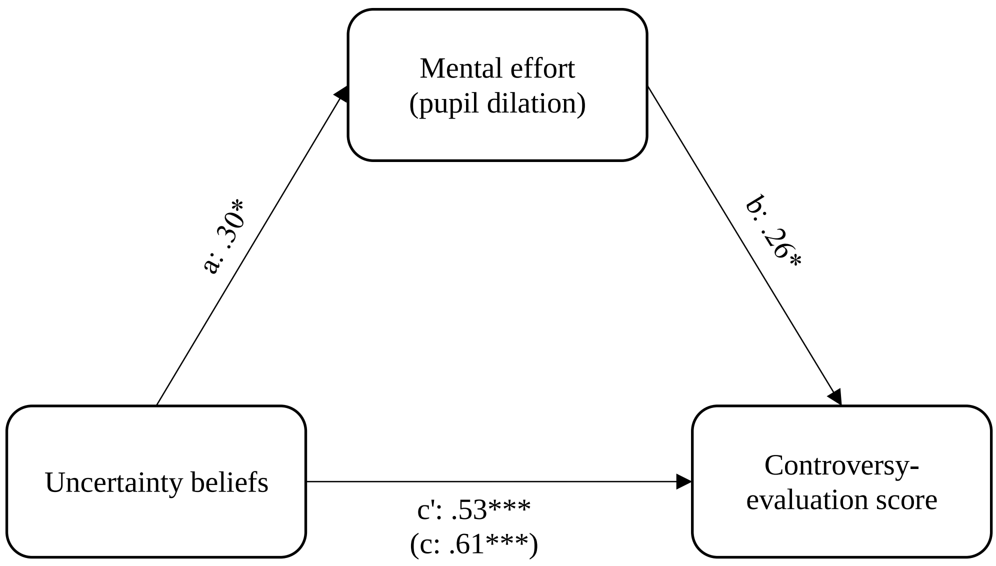

Figure 2.2 *Mediation of uncertainty beliefs on controversy-evaluation score through mental effort; *p < .05, **p < .01, ***p < .001*

Discussion

Today, laypeople are increasingly confronted with scientific controversies. Hence, if they want to make use of scientific findings, individuals need to critically juxtapose and integrate conflicting scientific knowledge claims in order to identify the underlying causes of a scientific controversy (Bromme & Goldman, 2014; Feinstein, 2011). In the present study, we investigated individuals' uncertainty beliefs in the domain of science (Conley et al., 2004) as a determinant for the evaluation of scientific controversies and the mediating role of mental effort. This idea was driven by the notion that individuals might be equipped with adequate beliefs, but that the enactment of these beliefs in a particular context is an effortful process. Hence, approximately one week after assessing their uncertainty beliefs, we had participants complete a controversy-evaluation test in which they were asked to evaluate the underlying causes of five scientific controversies in terms of theoretical, methodological, and ethical aspects. Moreover, we measured participants' amount of invested mental effort during test taking as indicated by their pupil dilation.

First, our results indicate that uncertainty beliefs do contribute to the evaluation of scientific controversies, as they were strongly associated with participants' controversy-evaluation performance. That is, individuals who believe in uncertain, tentative, and evolving knowledge tended to outperform those holding beliefs in certain, absolute, and unchanging knowledge when it came to evaluating potential reasons for scientific controversies (Hypothesis 1). This finding is in line with previous research linking uncertainty beliefs to aspects that are typical for scientific controversies, such as solving ill-defined problems (Schraw et al., 1995) or drawing inferences from multiple texts (Strømsø et al., 2008).

Another finding was that individuals' uncertainty beliefs also determined the amount of mental effort invested when reading the scientific controversies (Hypothesis 2). While previous research directly linking uncertainty beliefs to mental effort yielded inconclusive results (cf. Scheiter et al., 2009; Yang et al., 2016), it is implicit in many existing studies that individuals who believe in uncertain knowledge also show increased mental effort when solving a task (e.g., Hofer, 2004; Pieschl et al., 2008). In the present study, we were able to demonstrate this relationship for pupil dilation as an indicator of mental effort.

Mental effort itself was also positively associated with the controversy-evaluation test, in the sense that the more effort participants invested, the better their test scores were (Hypothesis 3). This result is in line with previous research showing that mental effort is a predictor of performance measures, given that task difficulty is not too high (Paas et al., 2005; Paas & van Merriënboer, 1993). Since the controversy-evaluation test we used in this study was initially developed for high-school students (Kramer et al., 2019; Oschatz et al., 2017), it is unlikely that the task was too difficult for our sample of undergraduate university students.

With Hypothesis 4, we showed that mental effort mediates the effect of uncertainty beliefs on the controversy-evaluation score. This result suggests that individuals believing in uncertain knowledge were more eager to dedicate mental effort to a task in which their uncertainty beliefs were called upon, such as the evaluation of conflicting knowledge claims. This, in turn, led to better evaluation performance. We found evidence for a partial, and not a complete mediation. A possible posthoc interpretation of this result is that when individuals acknowledge uncertainties, they also possess the will to engage in deep cognitive processing when they encounter situations for which their beliefs are adaptive. In the case of the present study, participants who believed in uncertain knowledge invested more mental effort when tasked to evaluate contradictory knowledge claims. However, it seems plausible that uncertainty beliefs play a role for the evaluation of scientific claims over and above this indirect effect (cf. Barzilai & Zohar, 2012; Strømsø et al., 2008). Caution is warranted, however, when interpreting the mediation results as causal effects. Even though the proposed model seems theoretically plausible, and we measured participants' uncertainty beliefs approximately one week in advance and mental effort during test-taking, we cannot completely rule out other possible mechanisms of how the evaluation of conflicting claims can be affected, such as through increased attention to source information (Kammerer, Kalbfell, & Gerjets, 2016) or better memory for contradictions (Stadtler, Scharrer, Brummernhenrich, & Bromme, 2013).

Implications and further research

From a broader perspective, the present study has some implications for the role of uncertainty beliefs and mental effort in the context of scientific controversies, in terms of theory, methodology, and educational practice.

Regarding theory, results suggest that uncertainty beliefs play an important role for the proficient evaluation of scientific controversies, in the sense that participants holding beliefs in uncertain knowledge were better able to identify plausible underlying causes for the controversies they were confronted with. While our results indicate that uncertainty beliefs are beneficial when individuals are confronted with competing scientific claims, past research has also shown that the adaptiveness of individuals' epistemic beliefs can vary depending on the context (Bråten, Strømsø, & Samuelstuen, 2008). Future studies should therefore investigate whether our results hold for other contexts as well, for example regarding different knowledge domains such as history or philosophy. Moreover, the finding that mental effort, but not reading time measures, were associated with better task performance, is in line with our conceptualization of mental effort as deep cognitive processing rather than extensive reading.

By investigating the mediational mechanism of individuals' uncertainty beliefs and mental effort, we also accounted for calls for theoretical clarification regarding processes that are related to these beliefs (Bråten et al., 2011). Future research should further reveal the mechanisms of how these and other variables interact. For example, motivational variables such as epistemic motivation, epistemic doubt, or situational interest might be useful to further explain the relationship between uncertainty beliefs and mental effort (e.g., Kienhues, Bromme, & Stahl, 2008; Mason et al., 2008; Mussel, Ulrich, Allen, Osinsky, & Hewig, 2016). Furthermore, bidirectional relationships might exist. Not only might uncertainty beliefs be beneficial for dealing with scientific controversies, but also might being exposed to scientific controversies, in turn, serve as an intervention to foster those beliefs (Kienhues, Ferguson, & Stahl, 2016). In summary, although more theoretical clarification is needed, our study contributes to explaining how uncertainty beliefs and mental effort work together in the important field of scientific controversies.

From a methodological perspective, the present study adds to prior research by triangulating online and offline measures to gain new insights into how individuals evaluate conflicting scientific information. Our study shows that it can be worthwhile to use eye-tracking technology to obtain indicators of mental effort, and that combining this information with traditional questionnaire measures can add to our understanding of epistemic cognition.

One shortcoming of the present study relates to aspects of the sample. Due to its time-consuming data collection and preparation, eye-tracking comes along with certain constraints regarding sample size. Moreover, in the present study we investigated university students because of the high relevance of scientific controversies for this target group. However, even though we focused on university entrants, we cannot rule out the possibility that participants were already more familiar with evaluating controversial scientific claims than the general population. Therefore, future research will need to replicate our results based on different age groups and educational levels and larger samples.

Furthermore, despite ample evidence that pupil dilation is associated with effortful cognitive processing, there could be other factors that have an effect on pupil size. While physical factors such as lighting conditions and screen distance were held constant, we did not account for other variables on the side of the participants that might influence pupil dilation such as emotional arousal (Bradley, Miccoli, Escrig, & Lang, 2008). Future studies should therefore employ additional indicators of mental effort such as EEG data (Scharinger et al., 2015) to further validate this measure and to triangulate the results.

Finally, the present study also bears implications for educational practice. The finding that individuals' uncertainty beliefs and mental effort determine their understanding of scientific controversies gives cause for optimism. Control variables such as reading comprehension ability or conscientiousness did not yield significant results. While fostering the latter in students can be a tedious endeavour, individuals' belief system and the effort they invest into a task are susceptible to change. Intervention studies have shown, for example, that advanced epistemic beliefs can be fostered (Ferguson, Bråten, Strømsø, & Anmarkrud, 2013; Gill et al., 2004; Kammerer, Amann, & Gerjets, 2015; Kienhues et al., 2008; Muis & Duffy, 2013). While Muis and Duffy (2013) demonstrated the effectiveness of a whole university course designed to foster students' epistemic beliefs, Kienhues et al. (2008) showed that students' beliefs can even change after receiving a short-term refutational instruction (focusing on doubting the certainty of scientific propositions). The challenge for educators will then be to question their own beliefs regarding the uncertainty of scientific knowledge in order to function as a role model for their students, and to provide their students with learning possibilities adaptive to their beliefs. Promoting advanced beliefs is not only a means to prevent misconceptions about science, but also to promote learning and critical thinking skills in general (Greene & Yu, 2016; Sinatra et al., 2014). In order to increase students' mental effort during reading, it would be advisable to use (or develop) learning material that is neither over- nor underchallenging and that motivates students to interact with the content in an effortful process. Such material might include scientific controversies or the juxtaposition of scientific theories and everyday theories. Educators can also promote mental effort in students by using instructions demanding critical thinking (Heijltjes, van Gog, Leppink, & Paas, 2015). In broader terms, educators should bear in mind how student engagement is affected by students' beliefs and, in turn, affects their learning outcomes (Azevedo, 2015).

Conclusion

In sum, using conflicting scientific information as a conceptual framework, the present study demonstrated that students' uncertainty beliefs and the investment of mental effort can explain a large degree of their performance when evaluating scientific controversies. Promoting individuals' uncertainty beliefs as well as their effort to make use of them when being confronted with scientific controversies is therefore a worthwhile endeavour to give individuals the chance to become responsible and scientifically literate citizens in today's knowledge society.

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3

Study 2

Different Indicators of Cognitive Engagement and Their Relation to Evaluating Scientific Controversies

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Abstract

Cognitive engagement is a central construct used in educational research to predict learning processes and outcomes. However, existing conceptualizations are inconsistent, and research on cognitive engagement in the domain of science is underrepresented. In the present study we focused on the evaluation of scientific controversies, integrating different prominent indicators of general and situational cognitive engagement using questionnaire measures and eye-tracking technology. Specifically, we examined (1) whether indicators of general and situational cognitive engagement are interrelated, (2) how these indicators relate to other relevant variables, and (3) whether general and situational cognitive engagement predict the evaluation of scientific controversies. Based on a sample of $N = 40$ university science students, we found that (1) general and situational cognitive engagement are independent; (2) general cognitive engagement was uniquely correlated with science interest and situational cognitive engagement was uniquely correlated with reading comprehension ability; and (3) general cognitive engagement, but not situational cognitive engagement, predicted the evaluation of scientific controversies. This study discusses the implications of the conceptualization and measurement of cognitive engagement and provides recommendations for educational practice and future research.

Keywords: cognitive engagement; scientific controversies; eye tracking; pupil dilation

Introduction

Engagement has become a major topic of interest for both practitioners and researchers who aim to improve science learning and achievement (Boekaerts, 2016; Finn & Zimmer, 2012; Yazzie-Mintz & McKormick, 2012). Special issues of *Educational Psychologist* (2015) and *Learning and Instruction* (2016) have been dedicated to theoretical frameworks, measurements, and practical implications of the engagement construct. Engagement has been shown to affect both learning processes and outcomes (Fredricks, Blumenfeld, & Paris, 2004; Pietarinen, Soini, & Pyhältö, 2014; Wang & Eccles, 2012). However, despite the multitude of studies focusing on engagement, there is little theoretical and methodological clarity regarding the definition and measurement of engagement (Azevedo, 2015; Fredricks, Filsecker, & Lawson, 2016; Reschly & Christenson, 2012). There is no agreed-upon definition when differentiating dimensions of engagement (Eccles, 2016), and the extent to which—or even if—the multitude of engagement indicators in the literature are interrelated remains unclear (Henrie, Halverson, & Graham, 2015).

Following calls for more detailed analyses of engagement in a given context, the present study focuses on cognitive engagement in the domain of science (Azevedo, 2015; Fredricks, Filsecker et al., 2016; Sinatra, Heddy, & Lombardi, 2015). More specifically, we assessed indicators of general and situational cognitive engagement and investigated their interrelations as well as their role in the evaluation of scientific controversies.

Cognitive engagement

Individuals who are engaged in learning or completing a task are characterized by increased involvement or commitment, which affects the ways in which they approach the information they encounter (Finn & Zimmer, 2012). Hence, engaged individuals differ from disengaged individuals in terms of not only how they attend to a certain task but also the results they produce (Greene & Miller, 1996; Janosz, 2012). High engagement has been associated with academic achievement (Bathgate & Schunn, 2017; Fredricks et al., 2004; Greene & Miller, 1996; Pintrich & de Groot, 1990) as well as students' well-being (Pietarinen et al., 2014) and persistence (Fredricks et al., 2004; Kuh, Cruce, Shoup, Kinzie, & Gonyea, 2008).

Following the seminal literature review by Fredricks et al. (2004), there is broad agreement that there are at least three dimensions of engagement: cognitive, behavioral, and emotional engagement. These dimensions are not distinct, but they each influence learning processes and outcomes in different ways (Fredricks, Filsecker et al., 2016; Schmidt, Rosenberg, & Beymer, 2018). Cognitive engagement involves mental states and processes that are associated with deep, effortful, and sustained processing (Greene, 2015). Behavioral engagement generally involves overt actions associated with strong commitment, such as taking notes while reading or participating in extracurricular activities (Fredricks et al., 2004). Finally, emotional engagement involves identification with or affective states directed toward a certain content, activity, or institution (Pietarinen et al., 2014).

The engagement construct depicted here considerably overlaps with other prominent educational constructs, such as self-regulated learning (Corno & Mandinach, 1983; Wolters & Taylor, 2012) and motivation (Martin, 2007; Pintrich & Schrauben, 1992; Walker, Greene, & Mansell, 2006). Cognitive engagement in particular has similarities to these constructs (Corno & Mandinach, 1983; Renninger, Ren, & Polman, 2018; Wolters & Taylor, 2012), and some studies have even used indicators of motivation or self-regulation to measure cognitive engagement (see Appleton, Christenson, Kim, & Reschly, 2006). There are, however, certain characteristics that can help differentiate engagement from self-regulation and motivation. While self-regulated learning can be regarded as a goal-directed, intentional process (Wolters & Taylor, 2012), individuals can also be cognitively engaged in heteronomous tasks. Similarly, motivation refers to individuals' basic intentions, and engagement can be described as the actions that arise from those intentions (Cleary & Zimmerman, 2001; Fredricks & McColskey, 2012; Lau & Roeser, 2002; Moreno & Mayer, 2007).

In addition to their distinction from related constructs, several other facets make it complicated to create a conclusive definition of engagement (Appleton, Christenson, & Furlong, 2008; Azevedo, 2015; Eccles, 2016; Sinatra et al., 2015). It is necessary to clarify which dimension of engagement (cognitive, behavioral, emotional, or a combination thereof) is being measured as well as the contextual features that influence engagement (Fredricks et al., 2004; Lam, Wong, Yang, & Liu, 2012). For example, individuals' reading skills have to be considered, especially when investigating cognitive engagement during reading tasks (Miller, 2015; Stine-Morrow, Soederberg Miller, Gagne, & Hertzog, 2008). Further, domain-specific and domain-general aspects of engagement need to be differentiated, and the grain size of the dimension of interest needs to be made clear (Sinatra et al., 2015). That is, are we measuring engagement on a general level or in a certain context or situation? Where on the state–trait continuum do we locate our conceptualization of engagement? Despite—or maybe because of—the popularity of the engagement construct, these issues are neglected in the engagement literature more often than not, undermining the usefulness of the engagement construct (Azevedo, 2015; Eccles, 2016; Reschly & Christenson, 2012). In other words, there appears to be a "tension between conceptual clarity and practical reality" (Fredricks et al., 2004, p. 84), or between a detailed investigation of a particular facet of engagement and a broad investigation of engagement (see also Eccles & Wang, 2012). Given the conceptual fuzziness in engagement research, the present study can be placed on the former end of this continuum. Focusing on conceptual clarity, we perform in-depth analyses of one engagement dimension (cognitive engagement) in a particular context (science). We define cognitive engagement as the effortful and sustained mental processing of individuals at both a general and situational level, going beyond mere understanding and aiming at elaboration, integration, and mastery (Aubteen Darabi, Nelson, & Paas, 2007; Finn & Zimmer, 2012; Greene, 2015; Miller, 2015). Moreover, the enactment of cognitive engagement depends on contextual factors, such as the respective topic, instruction, or goals (Fredricks, Filsecker et al., 2016; Meece, Blumenfeld, & Hoyle, 1988; Pugh, Linnenbrink-Garcia, Koskey, Stewart, & Manzey, 2010; Ravindran, Greene, & DeBacker, 2005). Using a relatively narrow definition like this might limit the range of applications of the engagement construct, but it allows for a more rigorous empirical examination (Eccles & Wang, 2012). Bearing this in mind, in the present study we assessed well-established measures of cognitive engagement from different research traditions and investigated how these measures are interrelated when university science students evaluate scientific controversies.

Cognitive engagement in science

In an era in which scientific information is broadly accessible on the Internet and scientific issues are becoming more and more important in everyday life, individuals need to be cognitively engaged with science if they are to make informed decisions (Goldman & Scardamalia, 2013; National Research Council, 2012; OECD, 2007). Laypeople are often confronted with contradictory knowledge claims that require thorough and effortful evaluation—that is, cognitive engagement—in order to be harnessed (Sinatra & Hofer, 2016). However, studies have documented that students become less engaged in science over their school careers (e.g., Osborne, Simon, & Collins, 2003; Patall, Vasquez, Steingut, Trimble, & Pituch, 2016; Vedder-Weiss & Fortus, 2011). Given this decline in science engagement on the one hand and the growing importance of cognitive engagement with potentially inconsistent scientific information on the other hand, it is surprising that only a few studies have explicitly investigated cognitive engagement in the domain of science (see also Schmidt et al., 2018). Accordingly, there is little consensus regarding how cognitive engagement should be defined and measured in science (Azevedo, 2015; Sinatra et al., 2015).

When investigating cognitive engagement in science, it is important to consider how it affects individuals when they take part in scientific practices (Azevedo, 2015; Kuhn, Arvidsson, Lesperance, & Corprew, 2017). Prior research has shown that cognitive engagement in science is relatively stable across different science-related practices, such as hands-on lessons, taking a science test, or extracurricular activities (Ben-Eliyahu, Moore, Dorph, & Schunn, 2018; Lau & Roeser, 2002). Because cognitive engagement in science is naturally directed toward certain scientific content, motivational constructs have to be considered as well (Corno & Mandinach, 1983; Fredricks, Hofkens, Wang, Mortenson, & Scott, 2018; Renninger et al., 2018). Given the conceptual overlap with motivation, it is unsurprising that several studies found relations between measures of motivation and cognitive engagement during science-related practices, such as reading scientific texts or science learning (Bathgate & Schunn, 2017; Ben-Eliyahu et al., 2018; Guthrie et al., 2004). Other studies have identified science interest to be an important prerequisite for cognitive engagement (Patall et al., 2016; Renninger & Bachrach, 2015). Even though most of the studies cited above were correlational, from a theoretical perspective, it seems plausible that related constructs, such as science interest, may serve as antecedents of cognitive engagement in science. That is, only with intrinsic drive can individuals muster the cognitive engagement needed to process scientific content (Blumenfeld, Kempler, & Krajcik, 2006; Cleary & Zimmerman, 2001; Pintrich, 2003).

As Greene (2015) pointed out, there is not only lack of research focusing on antecedents of cognitive engagement but also a lack of studies investigating the consequences of cognitive engagement, that is, the ways in which cognitive engagement affects the content to which it is directed (see also Janosz, 2012). An important science-related practice is evaluation and integration of contradictory scientific knowledge claims (Alongi, Heddy, & Sinatra, 2016). Evaluating scientific controversies is a key issue both inside and outside the classroom if individuals are to make use of scientific knowledge (Greene & Yu, 2016; Sandoval, Greene, & Bråten, 2016; Sinatra, Kienhues, & Hofer, 2014). Given the tentative nature of scientific concepts, research on conceptual change can be seen as preliminary evidence of the importance of cognitive engagement in the processing of contradictory information. Studies by Dole and Sinatra (1998) and Heddy and Sinatra (2013) showed that an increase in cognitive engagement was associated with more elaborate conceptual change in students.

According to Fredricks et al. (2004), cognitive engagement consists of general and situational aspects. Other research has also differentiated between macro engagement on the one hand and micro engagement, or task engagement, on the other hand (Lee & Anderson, 1993; Sinatra et al., 2015). Notably, previous studies on cognitive engagement in science, although scarce, have mainly focused on general engagement and, in some cases, failed to clearly distinguish between the general and situational aspects of cognitive engagement. The distinction between general and situational aspects has important implications for the conceptualization and measurement of cognitive engagement. That is, the conceptual grain size of cognitive engagement needs to be aligned with appropriate measurement approaches (Azevedo, 2015; Sinatra et al., 2015). The following section summarizes prominent measures that have been used to assess general or situational cognitive engagement.

General and situational measures of cognitive engagement

Not only has cognitive engagement been inconsistently defined in the literature but also varying measurement approaches have been applied. Cognitive engagement has often been used as an umbrella term for different indicators (Finn & Zimmer, 2012; Fredricks & McColskey, 2012), although some researchers have made efforts to categorize different conceptualizations of cognitive engagement and their respective measurement approaches. For example, Azevedo (2015) classified different indicators of cognitive engagement according to the underlying data source, differentiating between self-reports, process measures, and products. In the present study, we focused on self-reports and process measures as indicators of cognitive engagement. However, a comprehensive overview of cognitive engagement measures is beyond the scope of the present paper, so interested readers should see Fredricks and McColskey (2012) and Henrie et al. (2015). Note that some of the instruments listed in these reviews incorporate indicators of cognitive engagement that more aptly describe self-regulated learning and motivation, such as perceived value or strategy use. In fact, some studies on cognitive engagement adopted instruments that were initially developed to measure other constructs (e.g., Appleton et al., 2006; Pintrich & de Groot, 1990). In the present study, we focused on measures that comply with our own definition of cognitive engagement as effortful processing and do not represent related constructs.

General cognitive engagement is usually assessed using self-report measures (for an overview, see Greene, 2015) that are not situation-specific, but can be generalized to different contexts (Fredricks et al., 2004). Self-report measures of general cognitive engagement are based on the underlying assumption that individuals can provide information about their level of engagement. Besides being easy to distribute, self-reports have the advantage of measuring self-perceptions of processes that would be hard to observe otherwise (Henrie et al., 2015). One example for measuring general cognitive engagement with self-reports comes from Greene and Miller (1996), who used two scales to measure meaningful and shallow cognitive engagement in formal learning contexts. More recently, Wang, Fredricks, Ye, Hofkens, and Linn (2016) introduced domain-specific questionnaires for engagement in math and science, which showed good psychometric properties and allowed for differentiation of teachers' and students' perspectives. Rather than distinguishing between deep and shallow processing strategies, the instrument developed by Wang et al. (2016) identifies high to low general cognitive engagement in math and science on a continuum.

Situational cognitive engagement has been measured with both self-reports and process measures. One example of a self-report measure that assesses situational cognitive engagement was developed by Paas, and this single-item scale has been used extensively in the cognitive load literature (Paas, 1992; Paas, Tuovinen, Tabbers, & van Gerven, 2003). Individuals state the amount of mental effort they invested after a task or at multiple points during a task. Even though cognitive load research is not typically concerned with the engagement construct, the conceptual similarities between mental effort and cognitive engagement are apparent (Fredricks, Filsecker et al., 2016; Greene, 2015; Guthrie, Wigfield, & You, 2012). Accordingly, effortful cognitive processing is at the core of our definition of cognitive engagement.

As for process measures of situational cognitive engagement, advancements in eye-tracking technology provide a nonintrusive situational approach (Lai et al., 2013; Miller, 2015; Wang, 2011). Because cognitive engagement does not necessarily translate into overt actions, conventional observational measures are not appropriate (Eccles, 2016; Henrie et al., 2015). However, eye-tracking measures have been used across different research traditions as a means to investigate the amount of cognitive resources individuals invest during a task (Boekaerts, 2017; Paas, Ayres, & Pachman, 2008). First, eye tracking can reveal fine-grained variations in individuals' pupil diameter. An extensive body of research has shown that pupil dilation is linked to effortful cognitive processing, that is, cognitive engagement (Beatty, 1982; Beatty & Wagoner, 1978; Hyönä, Tommola, & Alaja, 2007; Korbach, Brünken, & Park, 2017; Marshall, 2005; Scharinger, Kammerer, & Gerjets, 2015; van der Wel & van Steenbergen, 2018). Second, eye-tracking technology allows one to assess fixation time measures that indicate cognitive engagement (Holmqvist et al., 2011; Liversedge, Paterson, & Pickering, 1998; Matthews, Reinerman-Jones, Barber, & Abich, 2015). According to the eye-mind assumption (Just & Carpenter, 1980), the duration for which individuals inspect information is directly linked to the encoding of information and allocation of mental resources, that is, cognitive engagement. Using measures comparable to fixation duration, previous research has examined time-on-task and reading time as indicators of situational cognitive engagement (e.g., Fisher et al., 1981; Miller, 2015; Peterson, Swing, Stark, & Waas, 1984).

Thus, three different facets of cognitive engagement can be differentiated in prior literature: (a) general cognitive engagement, (b) self-reported situational cognitive engagement, and (c) process-related situational cognitive engagement. Prior research has often insufficiently justified the methods chosen to measure cognitive engagement, and too many studies relied on a single measure of cognitive engagement (see also Appleton et al., 2008; Azevedo, 2015; Eccles, 2016). A promising avenue for future research is triangulation of multiple methods in order to gain a more differentiated picture of the complex nature of individuals' cognitive engagement in a given context (Fredricks & McColskey, 2012; Salmela-Aro, Moeller, Schneider, Spicer, & Lavonen, 2016). Studies that did use multiple indicators of cognitive engagement found small to moderate correlations between measures (Peterson et al., 1984; Wigfield et al., 2008). However, this stream of research did not clearly distinguish cognitive engagement from other dimensions, such as behavioral engagement, or related constructs, such as self-regulation. Rather than simply juxtaposing as many methods as possible, researchers must determine the grain size of cognitive engagement that they aim to measure and perform a well-founded selection of suitable measures (Azevedo, 2015; Eccles & Wang, 2012). By defining and measuring three different indicators of cognitive engagement (i.e., general, self-reported situational, and process-related situational), the present study provides an example of how this can be achieved.

The present study

Cognitive engagement is a popular construct in educational research. However, to date, several aspects have not been adequately investigated. First, past studies have insufficiently addressed cognitive engagement in the domain of science (Azevedo, 2015; Greene, 2015). Hence, the present study investigated how individuals evaluate scientific controversies as a means to measure cognitive engagement in science. Furthermore, whereas most prior studies focused on the prerequisites of cognitive engagement, little is known about its consequences (Eccles, 2016; Greene, 2015). Accordingly, in the present study, we investigated the role of cognitive engagement in the evaluation of scientific controversies. Third, whereas past research usually captured multiple dimensions of engagement using a single method, in this study we measured cognitive engagement with several indicators, thus providing a differentiated view and more conceptual clarity regarding this dimension of engagement (Fredricks et al., 2004; Salmela-Aro et al., 2016). Finally, prior educational research has almost exclusively addressed school engagement among a narrow age cohort (see also Ben-Eliyahu et al., 2018). Eccles and Wang (2012) assumed that individuals might display different forms of cognitive engagement after childhood. Hence, the present study investigated cognitive engagement among young adults in a university context. In summary, we analyzed different indicators of cognitive engagement in science in order to clarify their conceptual relations as well as their role in evaluating scientific controversies.

With our first research question we explored the interrelations different indicators of cognitive engagement (general-professed, situational-professed, and situational-enacted). Given the novelty of this approach, we did not specify hypotheses regarding the strength and direction of the relations between different indicators.

Delineating the different indicators of cognitive engagement from related constructs is the next step towards conceptual clarity. Therefore, our second research question concerned the relation between cognitive engagement and two constructs that have been shown to correspond with cognitive engagement. First, as stated above, cognitive engagement and motivation have not been clearly distinguished in prior research. Hence, we investigated the relation between cognitive engagement in science and science and interest as variables on the motivational spectrum (see also Renninger et al., 2018). Second, because our research context involved reading and evaluation of contradictory scientific information, we tested whether reading comprehension ability would have an impact on cognitive engagement. Miller (2015) has linked cognitive engagement to theories of reading, stating that proficient readers are better able to strategically allocate their mental resources in challenging tasks. Specifically, we expected that general measures of cognitive engagement in science would be most strongly related to science interest because in both measures individuals state their typical preferences or behavior (Hypothesis 1.1; Skinner, Kindermann, Connell, & Wellborn, 2009). Situational measures of cognitive engagement, on the other hand, were assumed to correspond to reading comprehension ability (Hypothesis 1.2) because reading difficulties during a task should affect individuals' situational, but not general, cognitive engagement. This hypothesis aligns with our definition that cognitive engagement involves—but goes beyond—merely understanding a text.

Finally, our third research concerned the influence of different indicators of cognitive engagement on the evaluation of scientific controversies. Specifically, we assumed that both individuals' general cognitive engagement regarding the domain of science and their situational engagement when reading about scientific controversies would be beneficial for evaluation of scientific controversies (Hypothesis 2).

Method

Participants

Participants were $N = 40$ university science students (mean age = 21.45 years; $SD = 2.60$; 50% female) at a large German university. Their majors were Physics (9), Biology (8), Nanoscience (7), Chemistry or Biochemistry (7), Geography (5), and Medicine or Pharmacy (4). Participants were recruited through an online database as well as flyers and email lists. They received 12 € for their participation. German was all participants' first language. The study was approved in advance by the local ethics committee. Participants gave their written consent at the beginning of the study.

Materials

Controversy-evaluation test. Given the context-bound nature of cognitive engagement (Ben-Eliyahu et al., 2018; Lam et al., 2012), we investigated evaluation of scientific controversies as a topic that is highly relevant to science learning both inside and outside the classroom. We presented participants with five controversial texts describing a scientific controversy between two scientists and various claims regarding central aspects of the controversy (Kramer, Oschatz, Wagner, Thomm, & Bromme, 2019). This controversy-evaluation test was an element of the National Education Panel Study (NEPS; Oschatz, Kramer, & Wagner, 2017) that assesses the ability to critically reflect on conflicting scientific issues by identifying plausible underlying causes of the controversies. Table 3.1 provides an overview of the titles, content, and lengths of the texts. As can be seen from the titles, the controversy-evaluation test covered a range of topics within the domain of science.

Each controversy was presented on one page on a computer screen ($M = 349.6$ words, $SD = 52.68$), which contained a short introduction to the topic followed by a description of the opposing perspectives of two fictitious scientists. Each controversy was accompanied by five to seven statements about the possible underlying causes of the controversy or conflicting claims. Participants were asked to judge these statements as correct or incorrect. For example, in the "Chemical plant" text, two chemists presented soil samples obtained from different distances from a chemical plant, resulting in contradictory claims as to whether the emissions were harmful. One of the chemists stressed that children playing close to the chemical plant would be in particular danger. One statement related to this controversy was "The argumentation of Scientist A would also be plausible if he didn't refer to playing children." To answer correctly (i.e., "yes"), participants had to recognize that in this case a reference to playing children was not a valid argument by itself because the plausibility of the arguments underlying the example

Table 3.1

Description of the texts about scientific controversies used in the controversy-evaluation test

Title of the controversy	*Content*	*Number of words*	*Number of items*
Nervous dogs	Two scientists argue about whether nervousness in dogs is best treated with behavioral training or medication.	369	5
Epigenetics	Two scientists argue about whether or not environmental influences can change DNA.	376	7
Marathon training	Two scientists argue about the effectiveness of a certain kind of marathon training.	273	6
Chemical plant	Two scientists argue about whether or not the emissions from a certain chemical plant are harmful.	309	7
Preimplantation diagnostics	Two scientists argue about the scientific and ethical aspects of genetic testing prior to implanting embryos.	410	7

was not affected by a reference to playing children. Items were carefully designed so that they could be solved by interested laypeople and did not require prior knowledge of the underlying topics or domains. The goal was to measure individuals' critical reflections on the plausible underlying reasons for the controversies regarding theoretical, methodological, and ethical aspects, with high scores indicating more proficient evaluation. Evaluation of multiple conflicting knowledge claims is an authentic scientific practice that has effectively been used as a framework to study cognitive engagement in prior research (Bråten, Anmarkrud, Brandmo, & Strømsø, 2014; Bråten, Brante, & Strømsø, 2018; List & Alexander, 2017; Yang, 2017). In total, the controversy-evaluation test consisted of 32 items and yielded acceptable reliability ($\alpha = .64$).

General cognitive engagement. We used a questionnaire recently developed and validated by Wang et al. (2016) to measure general cognitive engagement. The cognitive science engagement scale consisted of eight items (e.g., "I don't think that hard when I am doing work for science classes") with good reliability based on our sample ($\alpha = .80$). The wording of some items was slightly altered to achieve better correspondence to a university context. Items were answered on a 5-point Likert-scale, and negative items were recoded so that high values indicated high general cognitive engagement in science.

Self-reported situational cognitive engagement. After presenting each of the five scientific controversies, we asked participants how much effort they put into working on the controversy on a 7-point Likert scale (Paas, 1992), with high values indicating high self-reported situational cognitive engagement. The resulting five values were aggregated into an average score (α = .92).

Process-related situational cognitive engagement. Using eye-tracking technology, we were able to extract different process-related measures of participants' situational cognitive engagement. In order to differentiate between different parts of the controversy-evaluation test, we defined two areas of interest (AOIs) for each controversy, one surrounding the controversy text on the left-hand side of the screen (AOI "controversy") and one surrounding the accompanying items on the right-hand side (AOI "items"). We chose to distinguish these AOIs because prior research has shown that different parts of a test require different cognitive processes (Lindner et al., 2014). Figure 3.1 provides a schematic illustration of how the controversies were presented to participants.

Our first measure of process-related situational cognitive engagement was participants' pupil dilation. To measure this, we recorded participants' baseline pupil diameter during the calibration phase before presenting each of the five controversies. Then, pupil dilation was calculated as the percentage deviation of participants' average pupil diameter in the AOIs "controversy" and "items" from the baseline measure using the following formula:

$$(\text{pupil diameter AOI} - \text{pupil diameter baseline}) / \text{pupil diameter baseline} * 100$$

This resulted in a measure of task-evoked pupillary response for both AOIs, with an increase in pupil dilation indicating an increase in cognitive engagement (Beatty, 1982; van der Wel & van Steenbergen, 2018). Once again, the resulting values were aggregated for all five controversies.

Second, we used different fixation time measures as additional indicators of participants' process-based situational cognitive engagement. For the AOI "controversy," we calculated first-pass and second-pass fixation duration. In this AOI, first-pass fixation duration is defined as the amount of time for which participants fixated on the texts about the controversies before answering the items. Because we were interested in analyzing the two major elements of the test (i.e., the texts and accompanying items), we did not measure first-pass and second-pass fixation duration at the word or sentence level. Therefore, even if a participant reread parts of the controversy during the initial reading, it was included in the first-pass fixation duration for the AOI "controversy" (cf. Hyönä, Lorch, & Rinck, 2003; Rayner, 1998). Second-pass fixation

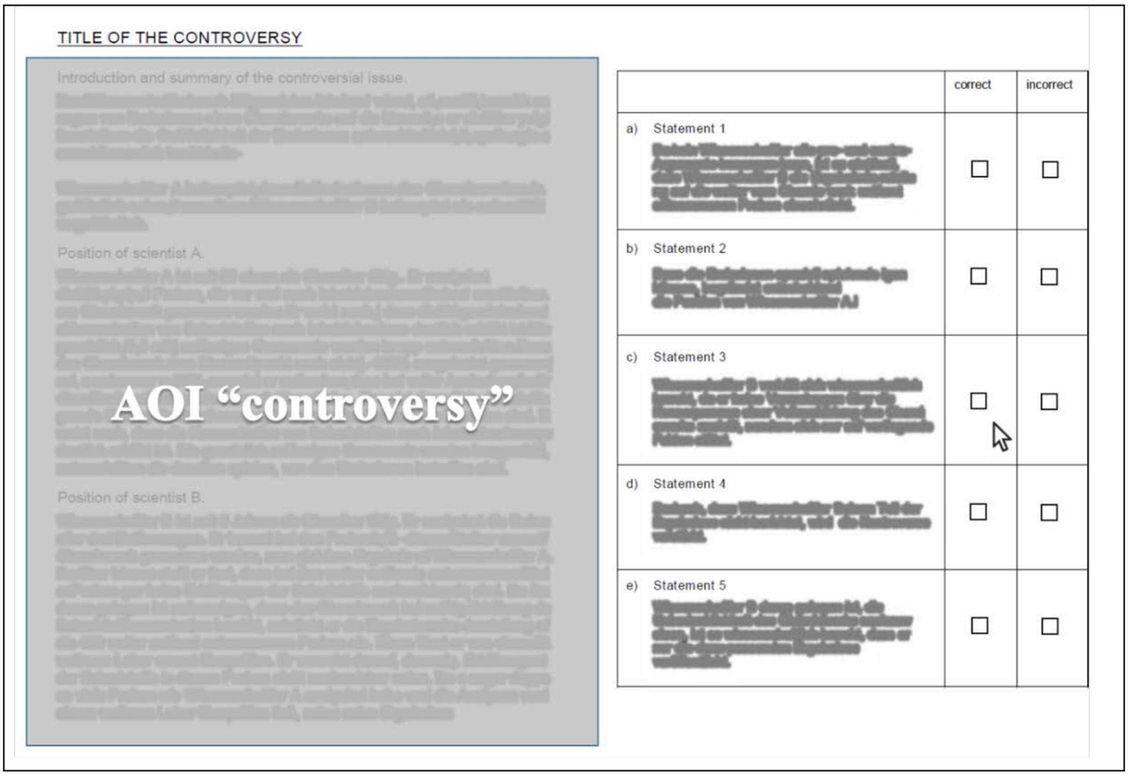

Figure 3.1 *Schematic illustration of a controversy from the controversy evaluation test with the AOI "controversy" superimposed*

duration, on the other hand, sums up all fixations back to the AOI “controversy” after the initial reading of the controversy. Of all 200 trials (40 participants evaluating 5 controversies each), in only one case did a participant scan the first two items before reading the controversy. All other participants first read the whole controversy and then moved on to the accompanying items. Whereas first-pass fixation duration indicates immediate cognitive engagement during information processing, second-pass fixation duration represents the cognitive engagement associated with rereading selective parts of a text when readers encounter difficulties, which involves delayed and more strategic allocation of attention (Holmqvist et al., 2011; Kaakinen, 2018; Liversedge et al., 1998; Miller, 2015). For the AOI “items” (i.e., the table on the right-hand side in Figure 1), it was not appropriate to differentiate between first- and second-pass fixation duration because participants frequently switched back and forth between the two AOIs (“items” and “controversy”) after the initial reading. Instead, we calculated the total fixation duration in this AOI, which included the sum of all fixations that occurred while participants worked on the items. Total fixation duration can be regarded as a composite measure of first- and second-pass fixation duration that represents participants’ average situational engagement during test-taking (Holmqvist et al., 2011; Yang, 2017).

Related constructs. The second research question addresses the relation between general and situational cognitive engagement and meaningful related constructs. First, to measure science interest, we used the *investigative* subscale of the German version of Holland's (1997) vocational interest inventory (Bergmann & Eder, 2005). The scale consisted of 10 items (α = .79), and participants expressed their preferences regarding different activities (e.g., "Reading scientific articles") on a 5-point Likert-scale. Second, we measured reading comprehension ability with a standardized German cloze test, LGVT 6-12 (Schneider, Schlagmüller, & Ennemoser, 2007). In this test, participants are given 4 minutes to underline up to 23 target words that are presented next to 2 false words. They receive 2 points for every correctly underlined word, -1 point for every incorrectly underlined word, and 0 points if no word was underlined, resulting in a reading comprehension score ranging from -23 to +46.

Procedure

Approximately one week before the lab sessions, we assessed the Wang et al. (2016) scale of cognitive science engagement as well as participants' science interest and demographics with an online questionnaire. Then, for the second part of the study, participants were tested in single sessions within a familiar environment (i.e., a lab on the science campus of their university). First, participants completed each of the five scientific controversies in the controversy-evaluation test consecutively on a computer screen. While they took the test, we recorded their eye movements using a 250-Hz remote eye-tracking system by SMI SensoMotoric Instruments. A chin rest was used to avoid head movements during data recording and to guarantee a fixed distance of about 70 cm between participants' eyes and the eye-tracking device. Fixations (and saccades) were detected with the saccade velocity detection algorithm from the default settings of the SMI BeGaze 3.5 software used for data processing. Each controversy in the controversy-evaluation test was presented successively as a separate trial on the screen. The accompanying items were presented simultaneously on the right-hand side of the screen and were answered by clicking a mouse. Participants were given 6 minutes per controversy to read the text and answer the accompanying items.[2] Before each trial, nine-point calibration of the eye-tracking system was performed. In cases of poor calibration, the trial was excluded from the analysis to improve data quality. At the end of each lab session, the test of reading comprehension ability was administered.

[2] Two participants slightly exceeded the time limit in the first two trials. They were given additional time to finish before moving on to the next controversy. All other trials were finished within the 6-minute time limit.

Results

Descriptive and correlational results

Table 3.2 provides an overview of the measurement approaches and abbreviations of the employed cognitive engagement measures. Descriptive statistics of these and all other measured variables are shown in Table 3.3. Note that all measures of situational cognitive engagement represent participants' mean engagement per controversy. Table 3.3 shows that, at the descriptive level, participants showed relatively high GCE and SSCE in relation to the measurement scale (GCE: M = 3.83, SD = 0.52, theoretical maximum of 5; SECE: M = 5.29, SD = 1.21, theoretical maximum of 7). Furthermore, the minimum values in Table 3.3 reveal that some participants showed low process-related situational engagement. The negative values for pupil dilation in both AOIs indicate that some participants were less engaged during test processing compared to the baseline, and the value of 0.18 seconds for second-pass fixation duration indicates that one participant did not look back at the texts at all after the initial reading.

Table 3.2

Cognitive engagement measures used in the present study

Facet of cognitive engagement	***Measure***	***Abbreviation***
General cognitive engagement	Wang et al.'s (2016) cognitive science engagement scale	GCE
Self-reported situational cognitive engagement	Paas' (1992) mental effort scale	SSCE
Process-related situational cognitive engagement	Pupil dilation on the AOI "controversy"	PD controversy
	Pupil dilation on the AOI "items"	PD items
	First-pass fixation duration on the AOI "controversy"	FFD controversy
	Second-pass fixation duration on the AOI "controversy"	SFD controversy
	Total fixation duration on the AOI "items"	TFD items

Table 3.3

Summary of descriptive statistics for all measured variables

Variable	*M (SD)*	*min*	*max*	*Skewness*	*Kurtosis*
GCE	3.83 (0.52)	2.88	5.00	0.00	-0.58
SSCE	5.29 (1.21)	1.80	7.00	-1.28	1.87
PD controversy (%)	0.26 (3.34)	-6.19	7.90	-0.01	-0.60
PD items (%)	3.92 (3.85)	-2.63	11.93	0.30	-0.87
FFD controversy (sec)	86.20 (22.65)	32.88	139.59	0.04	0.04
SFD controversy (sec)	10.37 (9.67)	0.18	46.49	2.10	5.39
TFD items (sec)	54.49 (18.45)	24.70	99.71	0.59	-0.41
Controversy-evaluation test score	24.95 (3.51)	14	31	-0.70	1.32
Investigative interest	3.64 (0.56)	2.50	4.70	-0.30	-0.80
Reading comprehension ability	20.13 (6.35)	7	33	-0.03	-0.28

Note. N = 40. Data regarding reading comprehension ability is missing for one participant, resulting in N = 39 for that variable. GCE = general cognitive engagement, SSCE = self-reported situational cognitive engagement, PD = pupil dilation, FFD = first-pass fixation duration, SFD = second-pass fixation duration, TFD = total fixation duration.

Research Question 1: The relation between different indicators of cognitive engagement

Guided by the first research question, we explored the relation between our indicators of cognitive engagement (GCE, SSCE, PD controversy, PD items, FFD controversy, SFD controversy, and TFD items). Preliminary analyses revealed moderate to high correlations within the different situational measures at the vignette level, indicating relatively high stability across the five scientific controversies ($.59 \leq r \leq .79$ for SSCE; $.49 \leq r \leq .63$ for PD controversy; $.43 \leq r \leq .71$ for PD items; $.61 \leq r \leq .79$ for FFD controversy; $.26 \leq r \leq .75$ for SFD controversy; and $.50 \leq r \leq .76$ for TFD items). Averaged across all five vignettes, PD items was considerably larger than PD controversy (t[39] = 8.79, p < .001, d = 1.39).

Table 3.4 depicts the aggregated scores for all measures of cognitive engagement over all five vignettes. As for the relation between the situational cognitive engagement measures, the results in Table 3.4 show a significant negative correlation between SSCE and PD items (r = -.32, p = .042), but no significant correlation between SSCE and PD controversy (r = -.15, p = .361). This indicates that the higher participants' reported situational engagement, the smaller their pupil dilation while fixating on the items. Besides the expectable correlations between the

Table 3.4

Summary of intercorrelations of all measured variables

Variable	1.	2.	3.	4.	5.	6.	7.	8.	9.
1. GCE	—								
2. SSCE	.11	—							
3. PD controversy (%)	.07	-.15	—						
4. PD items (%)	.15	-.32*	.74***	—					
5. FFD controversy (sec)	.11	.25	-.19	-.18	—				
6. SFD controversy (sec)	.15	.11	.07	-.18	.15	—			
7. TFD items (sec)	.15	.18	-.26	.28	.56***	.62***	—		
8. Controversy-evaluation test score	.50**	.15	.05	.19	-.05	.21	.15	—	
9. Investigative interest	.47**	-.16	.23	.23	-.01	.00	-.06	.14	—
10. Reading comprehension ability	-.03	-.26	.30†	.42**	-.50**	-.25	-.46**	.16	.26

Note. N = 40. Data regarding reading comprehension ability is missing for one participant, resulting in N = 39 for that variable. GCE = general cognitive engagement, SSCE = self-reported situational cognitive engagement, PD = pupil dilation, FFD = first-pass fixation duration, SFD = second-pass fixation duration, TFD = total fixation duration.
†$p < .10$, *$p < .05$, **$p < .01$, ***$p < .001$

two pupil dilation measures ($r = .74$, $p < .001$) and fixation duration measures ($r = .56$, $p < .001$ for the correlation between TFD items and FFD controversy; $r = .62$, $p < .001$ for the correlation between TFD items and SFD controversy), there were no significant correlations between the situational measures of cognitive engagement and GCE (all ps $\geq .342$).

Research Question 2: The relation between cognitive engagement and related constructs

Our second research question addressed the relation between cognitive engagement and related constructs in a science context. We predicted that GCE would be related to investigative interest (Hypothesis 1.1) and that the situational measures of cognitive engagement would be related to reading comprehension ability. Supporting Hypothesis 1.1, we found a high positive correlation between GCE and investigative interest ($r = .47$, $p = .002$). Investigative interest was not correlated with any of the situational measures of cognitive engagement (all ps $\geq .157$).

As for the situational cognitive engagement measures, we found no significant correlation between reading comprehension ability and SSCE ($r = -.25$, $p = .107$). However, there were significant correlations between reading comprehension ability and the process-related measures of situational cognitive engagement. Specifically, we found negative correlations between reading comprehension ability and two of the three fixation duration measures (r = -.50, p = .001 for FFD controversy; r = -.25, p < .130 for SFD controversy; r = -.46, p < .003 for TFD items). We also found (marginal) positive correlations between reading comprehension ability and the pupil dilation measures (r = .30, p = .066 for PD controversy; r = .42, p < .007 for PD items). Taken together, the results partially support Hypothesis 1.2 as they indicate that the higher participants' reading comprehension ability, the longer they fixated on the items and texts during the initial reading and the larger their pupil dilation was while fixating on the items.

Research Question 3: The influence of cognitive engagement on processing and evaluation of scientific controversies

Our third research question was concerned with how different indicators of cognitive engagement influence individuals' evaluations of scientific controversies. Specifically, Hypothesis 2 predicted that general and situational measures of cognitive engagement would be associated with better performance in the controversy-evaluation test. At the correlational level, we found a positive correlation between performance on the controversy-evaluation test and GCE (r = .50, p = .001), but no significant correlations with the situational measures of cognitive engagement (all ps ≥ .204). To test the relative influence of the different measures of cognitive engagement, we conducted multiple linear regression analyses (see Table 3.5). Regression coefficients before the dash represent controversy-evaluation test scores, which were used as the dependent variables. Additionally, we regressed the controversy-evaluation test score on reading comprehension ability and used the studentized residual variance—that is, the share of variance in controversy-evaluation test score that was not explained by reading comprehension ability—as an additional dependent variable (see also Miller et al., 2014). The coefficients of the studentized residuals are located behind the dashes. In all models, GCE positively predicted performance on the controversy-evaluation test, except in Model 4, where this coefficient was only marginally significant when the residual value of the controversy-evaluation test was used as a dependent variable (β = .36, p = .070). Moreover, when controlling for SSCE (Model 1), pupil dilation measures (Model 2), fixation duration measures (Model 3), and investigative interest (Model 4), the effect of GCE decreased only slightly. As in the correlational results, the measures of situational cognitive engagement were not related to the controversy-evaluation test score in any of the four models (all ps ≥ .127). At the descriptive level, controlling for reading comprehension ability (expressed by the studentized residuals behind the dashes) led to a slight decrease in GCE, PD controversy, and PD items and to a slight increase in SSCE and TFD items. Furthermore, the two pupil dilation measures as well as

Table 3.5

Linear regression analyses predicting controversy-evaluation test score with cognitive engagement

Dependent variable	Controversy-evaluation test score (left) / studentized residual of the controversy-evaluation test score after controlling for reading comprehension ability (right)			
	Model 1	**Model 2**	**Model 3**	**Model 4**
Predictor	β	β	β	β
GCE	.49** / .41**	.44** / .38*	.44** / .36*	.48* / .36†
SSCE	.10 / .19	.18 / .25	.20 / .24	.18 / .24
PD controversy (%)		-.20 / -.19	-.18 / -.15	-.18 / -.16
PD items (%)		.33 / .27	.32 / .25	.31 / .25
FFD controversy (sec)			-.21 / -.10	-.20 / -.10
SFD controversy (sec)			.06 / .07	.06 / .07
TFD items (sec)			.12 / .17	.11 / .17
Investigative interest				-.08 / .00
R^2	.26 / .22	.30 / .25	.34 / .29	.35 / .29

Note. *N* = 40. Data for reading comprehension ability was missing for one participant, resulting in N = 39 for that variable. GCE = general cognitive engagement, SSCE = self-reported situational cognitive engagement, PD = pupil dilation, FFD = first-pass fixation duration, SFD = second-pass fixation duration, TFD = total fixation duration.
†$p < .10$, *$p < .05$, **$p < .01$

FFD controversy and SFD controversy seem to point in opposite directions; while the coefficients of PD controversy had a negative sign, PD items had a positive sign, and while the coefficients of FFD controversy were negative, the coefficients of SFD controversy and TFD items were positive.

Discussion

In this study, we investigated the interrelations between different measures of cognitive engagement as well as their individual relevance when university science students were engaged in evaluation of scientific controversies. We differentiated between general cognitive engagement, self-reported situational cognitive engagement, and process-related situational cognitive engagement. The latter was measured using pupil dilation and fixation duration measures, whereas general and self-reported situational cognitive engagement were measured with self-reports. Using scientific controversies as the specific context and adopting a relatively narrow definition of cognitive engagement allowed us to conduct an in-depth investigation of this important construct (Fredricks et al., 2004; Sinatra et al., 2015). Whereas prior research has often used indicators of cognitive engagement that are not distinct from related constructs, such as self-regulation or motivation (see Henrie et al., 2015), we took care to include only measures that comply with the conceptualization of cognitive engagement as effortful cognitive processing. We argue that conceptual rigor can be conducive to identification of appropriate measures and help avoid the common practice of using the same indicators to measure cognitive engagement in one study and behavioral engagement in another study.

In summary, we found that self-reported and process-related situational cognitive engagement were partly correlated, but there were no correlations between general and situational cognitive engagement (Research Question 1). General cognitive engagement was associated with science interest, and situational cognitive engagement was correlated with reading comprehension ability (Research Question 2). Furthermore, we found that general cognitive engagement, but not situational cognitive engagement, was related to participants' performance on a controversy-evaluation test (Research Question 3). Below, we discuss the theoretical implications of these results in more detail.

Theoretical implications

The present study advances our understanding regarding the differential functioning of different facets of cognitive engagement. Our finding that general and situational cognitive engagement were differentially related to science interest and reading comprehension ability, respectively, emphasizes the importance of aligning the grain size of engagement measures (i.e., from general to situational) with that of the presumed correlates (Azevedo, 2015; Sinatra et al., 2015). The finding that general cognitive engagement was not correlated with either of the measures of situational cognitive engagement is another reason to exercise caution. Prior research has usually conceptualized the indicators used in this study more or less synonymously as cognitive engagement, but we demonstrated that these indicators might represent very different facets of cognitive engagement and should not be tarred with the same brush. Rather, the conceptual level(s) at which cognitive engagement is being measured and the effects that the indicators can be expected to have on other variables should be clarified. Regarding the interrelation of different measures of situational cognitive engagement, we found a negative correlation between SSCE and PD items. A possible explanation for this finding is that SSCE indicates participants' conscious involvement with the learning material, whereas PD items indicates the enactment of cognitive resources that are necessary for this task. Accordingly, there might be a compensatory relationship between SSCE and PD items. That is, the higher individuals' conscious engagement in a certain situation, the fewer cognitive resources they need to use. However, we are not able to further investigate this idea using our data. Surprisingly, none situational cognitive engagement measures were related to performance on the controversy-evaluation test. For SSCE, this finding is in line with prior research, which did not find relations between mental effort and reasoning performance (e.g., Heijltjes, van Gog, Leppink, & Paas, 2015). Regarding process-related situational cognitive engagement, the difficulty of the controversy-evaluation test might have been too low, as indicated by the relatively high mean test score in Table 3.4, which could have made the enactment of processing strategies associated with longer total fixation duration less beneficial.

The finding that reading comprehension ability was related to almost all situational cognitive engagement measures points toward an important implication regarding the nature of these measures. This study, in line with most prior research, regarded an increase in both pupil dilation and fixation duration as indicative of increased situational cognitive engagement. However, the association with reading comprehension ability indicates that there might also be maladaptive influences on these measures. That is, both pupil dilation and fixation duration might comprise positive aspects of engagement, such as intentional effortful processing, as well as negative aspects, such as having to cope with complex tasks. When accounting for reading comprehension ability in the regression models predicting controversy-evaluation test score, the influence of pupil dilation measures decreased while the influence of fixation duration measures increased. Bearing in mind that none of the coefficients reached statistical significance, this pattern of results might still indicate that skilled readers tend to benefit more from engagement during reading (as indicated by longer fixation duration) and need to exert fewer cognitive resources (as indicated by decreased pupil dilation). Given that these measures are influenced by not only genuine cognitive engagement but also individuals' skill level (as indicated by reading comprehension ability), it does not seem straightforward to interpret pupil dilation and fixation duration as indicators of pure cognitive engagement. First, if a considerable share of the variance of fixation duration measures is accounted for by reading comprehension ability, fixation duration is less likely to indicate cognitive engagement if it is defined as "dedicating resources above and beyond the level necessary for simple comprehension" (Miller, 2015, p. 34). Similarly, Goldhammer et al. (2014) found complex relations between time-on-task (which is comparable to fixation duration), individual skill level, and task difficulty. In problem solving tasks, time-on-task had a positive effect, increasing with task difficulty but decreasing with skill level. In reading tasks, however, time-on-task had a negative effect, decreasing with task difficulty but increasing with skill level. These results, in line with our own findings, suggest that there might be no unambiguous interpretation of fixation duration without other explanatory variables. Second, if an increase in pupil dilation is due to individuals' reading skills, the pupil dilation measure might not have been able to capture cognitive engagement, given the physiological limitations of the pupillary system (Beatty & Lucero-Wagoner, 2000). Using a different terminology to describe a similar phenomenon, cognitive load theory differentiates between the desirable mental effort individuals invest in a task on the one hand, and undesirable intrinsic load imposed by the task and extraneous load imposed by instruction on the other hand (Ayres & Paas, 2012; Kirschner, Kester, & Corbalan, 2011). If our measures of situational cognitive engagement comprise both positive and negative influences on cognitive engagement, it is unsurprising that they were not able to predict performance on the controversy-evaluation test over and above participants' reading skills. Presumably, intentional cognitive engagement and individual skill level are two sides of the same coin, and we were not able to differentiate them with the chosen indicators. Triangulating our process-related measures with concurrent verbal reports during test-taking might be a way to facilitate interpretation of these indicators. However, collecting these verbal data would have imposed additional constraints on participants' cognitive resources, which would have altered the results.

The finding that reading comprehension ability was correlated with first-pass fixation duration but not second-pass fixation duration suggests that proximal measures that are closely related to basic information processing, such as first-pass fixation duration, might be confounded with other cognitive variables. More distal and strategic measures, such as second-pass fixation duration, might be needed to capture "clean" situational cognitive engagement. In line with this reasoning, the coefficients of PD controversy and PD items as well as FFD controversy and TFD items had opposite valences when predicting performance on the controversy-evaluation test. This makes it reasonable to believe that, in different parts of a task, the same indicators of cognitive engagement signify different kinds of cognitive processing (see also Lindner et al., 2014).

In conclusion, general and situational cognitive engagement appear to be relatively distinct facets of engagement that are differentially related to other variables, such as science interest and reading comprehension ability. By juxtaposing multiple measures of cognitive engagement, we were able to obtain a more detailed picture of how this construct is related to other relevant variables. Assuming that general measures comprise a trait component of cognitive engagement and situational measures comprise a state component, the context we provided our participants may not have been sufficient to induce general cognitive engagement, while other science-related practices, such as scientific discussions or experiments, might have prompted this type of engagement (see also Ben-Eliyahu et al., 2018). Regarding situational measures, we were not able to fully capture cognitive engagement beyond individuals' skill level. Clearly, more research is needed to identify which indicators can help us understand cognitive engagement in different contexts (Appleton et al., 2008; Eccles, 2016; Samuelsen, 2012).

Practical implications

Even though the present study was focused on theoretical clarification and took place in a lab setting, our findings have some practical (albeit tentative) implications. Our study showed that general and situational cognitive engagement can appear quite dissimilar. Just as it is important for researchers to bear this distinction in mind, practitioners should reflect on whether they are addressing general or situational aspects when they promote students' cognitive engagement in science and then adapt their instruction accordingly (see also Lau & Roeser, 2002). Even though we did not find a relation between general and situational cognitive engagement in our specific study context, it seems plausible that repeatedly engaging individuals in scientific practices will lead to increased general science engagement in the long run. Furthermore, our results showed that reading comprehension ability is an important variable to consider regarding students' situational cognitive engagement. It is therefore important for educational practice to foster students' reading skills not only in language domains but also in the science domain if students are to engage with scientific information beyond merely understanding it (Alexander, 2012).

GCE had a strong positive correlation with performance on the controversy-evaluation test. Prior research has shown that asking students to engage in evaluation of scientific controversies can be effective in science instruction (Alongi et al., 2016; Hess, 2009), and engaging students in scientific practices, such as evaluation of scientific controversies, can promote a more advanced understanding of scientific concepts (Kuhn et al., 2017). Not only was higher GCE associated with more elaborate evaluations but also engaged students were shown to have higher science interest. Although no causal claims can be derived from our results, it is clear that cognitive engagement is associated with a number of positive effects. It is possible that, in the complex dynamics of formal and informal learning contexts, fostering cognitive engagement in science can have spillover effects and lead to these desirable outcomes.

Similarly, cognitive engagement might help to translate students' motivation into learning outcomes in science and beyond.

Limitations and future directions

The engagement construct has been used inconsistently in the literature (Boekaerts, 2016; Eccles, 2016; Reschly & Christenson, 2012). Whereas the present study provides more conceptual clarity, it also raises a number of questions, and some issues still need to be addressed. First, the correlational design of our study forbids us from drawing any firm causal conclusions. Additionally, by using larger sample sizes, it might be possible to detect effects that we did not find in our data. For example, general cognitive engagement might have only moderate relations to situational cognitive engagement in a specific context, and we may not have found correlations between general and situational cognitive engagement because our study design lacked the power to detect these relations. However, measuring situational engagement in authentic scientific activities is time-consuming, especially when non-intrusive methods, such as eye tracking, are employed. There is a trade-off between attaining large samples on the one hand and implementing situational measures that produce rich data on the other hand.

Second, we need to make some critical remarks about the engagement measures in this study. The value range of PD controversy, for example, indicates that some participants were less engaged during test processing than at our neutral baseline measure. One explanation might be that the task of reading contradictory knowledge claims was too familiar to our study participants and thus resulted in less engagement than if they were novices at this task (Kalyuga, Ayres, Chandler, & Sweller, 2003). Furthermore, despite ample evidence that pupil dilation is linked to effortful cognitive processing (e.g., van der Wel & van Steenbergen, 2018; Wang, 2011), it is hard to differentiate this small-grained measure from other influences (Miller, 2015). While we took care to provide the same lighting conditions and eye-screen distance for all participants, our results showed that cognitive variables, such as reading comprehension ability, can also influence pupil dilation. Hence, participants' actual pupil diameter might be the net effect of various individual and contextual factors.

Third, in the present study we offer a detailed investigation of one dimension of engagement. However, we have to acknowledge that reality is more complex and many other factors affect the extent to which—or even if—individuals are cognitively engaged (Lam et al., 2012). Future research might investigate whether different reading strategies (Hyönä, Lorch, & Kaakinen, 2002) can help determine whether our situational measures indeed represent cognitive engagement. Similarly, accounting for working memory capacity in future studies might help differentiate the positive aspects of cognitive engagement (i.e., intentionally dedicating one's mental resources to a task) from the negative aspects (i.e., being charged with too much mental workload to master a certain task beyond mere understanding; cf. Meghanathan, van Leeuwen, & Nikolaev, 2014). Other variables might serve as antecedents that influence the shape and direction of cognitive engagement. For example, individuals' motivation might influence whether they approach a particular subject (Blumenfeld et al., 2006), self-regulation strategies might help maintain cognitive engagement throughout goal-directed and autonomous processes (Boekaerts, 2016, 2017), and epistemic beliefs might set standards regarding the information or activities in which individuals will engage (Berland & Crucet, 2016; DeBacker & Crowson, 2006). Similarly, the notion that more engagement will always lead to better results might not always be appropriate. For example, a study by Greene, Dillon, and Crynes (2003) found that successful science students were able to adjust the level of engagement depending on the task at hand. That is, cognitive engagement alone is not likely to be sufficient for learning and achievement in science, and individuals must reflect on the underlying principles of science in order to make use of scientific information (Sinatra et al., 2015).

Future studies could replicate our results using different contexts with authentic learning settings. For example, Miller et al. (2014) found that alternative instructional contexts, such as preparing for a discussion, can trigger different forms of cognitive engagement. In addition, compared to working on a standardized evaluation test, individuals' engagement will likely differ when they choose to evaluate controversial issues that are meaningful to them and set their own goals regarding how they solve the task (Boekaerts, 2016; Schmidt et al., 2018).

Given the current status of engagement research, a distinct set of indicators of cognitive engagement is still a long way off. There are two pathways for future research to advance the cognitive engagement construct. First, more rigorous theoretical work is needed to develop a set of appropriate indicators of cognitive engagement (and other engagement dimensions) in science (and other contexts). The measures that arise from this could be accompanied by qualitative approaches, which might overcome the limitations of multivalent, observational engagement measures (Fredricks et al., 2018; Fredricks, Wang et al., 2016; Lee & Anderson, 1993). Second, modern machine learning approaches might help to identify indicators of cognitive engagement through algorithms rather than theory using non-intrusive real-time measures of cognitive engagement (Aslan et al., 2019; D'Mello, Dieterle, & Duckworth, 2017). In so doing, researchers might overcome the limitations of traditional measures, such as data loss due to aggregation or disruption of the learning process with intrusive assessment methods.

Maybe we need a dual strategy in which we develop stronger theoretical models of engagement from which we can derive appropriate methodological approaches and use automatized approaches to identify patterns of cognitive engagement in big datasets, which could , in turn, inform the refinement of engagement theories. The goal of different research traditions must be to join together and overcome the definitional and methodological patchwork that makes it so hard to compare findings across different engagement studies (Fredricks, Filsecker et al., 2016; Reschly & Christenson, 2012). This way, we might finally come to grips with this "elusive, emergent, and multifaceted concept" (Eccles, 2016, p. 72). We hope that the present study will motivate future researchers to conduct studies on cognitive engagement in science because we need to know more about this powerful construct if we want to improve science learning.

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4

Study 3

Investigating Professed and Enacted Epistemic Beliefs About the Uncertainty of Knowledge When Students Evaluate Scientific Controversies

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Abstract

Prior research on epistemic beliefs, that is, individuals' views about knowledge and knowing, has mainly focused either on individuals' professed beliefs (as reported in questionnaires) or on their enacted beliefs (as verbalized during task processing). However, little is known about the relation between professed and enacted epistemic beliefs. In the present study, we focused on beliefs about the uncertainty of science-related knowledge and investigated both professed and enacted beliefs in the context of evaluations of scientific controversies. Participants were $N = 79$ university students who first completed a questionnaire that targeted their professed uncertainty beliefs about science-related knowledge. Then, approximately 1 week later, they completed a standardized test in which they evaluated five scientific controversies. We used cued retrospective verbal reports to measure their enacted uncertainty beliefs while taking the test. Results revealed that professed and enacted uncertainty beliefs were interrelated and that both variables predicted individuals' performance with regard to the evaluation of scientific controversies. Furthermore, the effect of professed uncertainty beliefs on evaluation performance was partly mediated by enacted uncertainty beliefs. The findings of the present study point toward novel theoretical insights and educational implications regarding the relations between professed and enacted beliefs about the uncertainty of science-related knowledge and their role in individuals' evaluation of scientific controversies.

Keywords: epistemic beliefs, uncertainty of science-related knowledge, scientific controversies, cued retrospective verbal reports

Introduction

Individuals who intend to expand their knowledge or make personal decisions on the basis of scientific evidence are often confronted with competing knowledge claims, particularly when it comes to ill-structured scientific issues (Greene & Yu, 2016; Sinatra, Kienhues, & Hofer, 2014). Therefore, the ability to evaluate scientific controversies is crucial for laypeople as it ensures informed decisions and democratic participation (Carey & Smith, 1993; Kuhn, 2005). However, it is not possible for laypeople to know and understand all relevant scientific findings of any given subject. They must therefore develop the competence to weigh and evaluate the contradictory knowledge claims they encounter (Bromme & Goldman, 2014). Specifically, key to evaluating a scientific controversy is the ability to detect and interpret its underlying causes (Britt, Richter, & Rouet, 2014). Recent research has stressed the role of epistemic beliefs when evaluating conflicting scientific knowledge claims (Bråten, Britt, Strømsø, & Rouet, 2011; Greene & Yu, 2016; Sinatra & Hofer, 2016). Specifically, beliefs about the certainty or uncertainty of knowledge (Hofer & Pintrich, 1997) have been proposed to be related to how students evaluate conflicting information (Bråten et al., 2011). Two lines of previous research have focused on either individuals' professed epistemic beliefs or their enacted epistemic beliefs. Professed epistemic beliefs refer to personal views about knowledge and knowing (Hofer & Pintrich, 1997), usually measured by questionnaires (i.e., offline data). In contrast, data sources such as verbal reports have been used to capture individuals' enacted epistemic beliefs while engaged in certain tasks (i.e., online or process data). The relation between individuals' professed epistemic beliefs and their enacted epistemic beliefs, however, has remained unclear in most previous studies. Therefore, a major goal of the present study was to investigate the interplay of individuals' professed and enacted epistemic beliefs regarding the uncertainty of knowledge and how they related to the evaluation of scientific controversies, by using both online and offline data.

Epistemic beliefs

The term epistemic beliefs refers to individuals' personal views about knowledge and the process of knowing (Hofer & Bendixen, 2012; Hofer & Pintrich, 1997). A dominant line of epistemic belief research has identified systems of relatively independent belief dimensions (Hofer & Pintrich, 1997; Schommer, 1990) that target the nature of knowledge and knowing and include, for instance, beliefs about the certainty (or uncertainty) of knowledge or beliefs about the justification of knowledge. Beliefs about the certainty or uncertainty of knowledge (hereafter referred to as uncertainty beliefs) constitute a core dimension in most epistemic belief frameworks (Bromme, Kienhues, & Stahl, 2008; Trautwein & Lüdtke, 2007). Uncertainty beliefs target the nature of knowledge, ranging from views that knowledge is absolute and fixed (i.e., certain) to views that knowledge is tentative and evolving (i.e., uncertain; Hofer, 2001; Hofer & Pintrich, 1997). Prior research has linked uncertainty beliefs to successful learning and achievement (Cano & Cardelle-Elawar, 2004; Trautwein & Lüdtke, 2007), particularly in the domain of science (Conley et al., 2004; Elby et al., 2016; Winberg, Hofverberg, & Lindfors, 2019).

A promising approach for studying uncertainty beliefs in the domain of science lies in investigating how students deal with conflicting knowledge claims, or more specifically, how they evaluate scientific controversies (Bråten, Strømsø, & Ferguson, 2016; Flemming, Feinkohl, Cress, & Kimmerle, 2015). Even though believing in uncertain knowledge might not be advantageous under all circumstances (Sinatra et al., 2014), acknowledging the uncertainty of scientific knowledge appears to be an important prerequisite for individuals to compare and evaluate multiple conflicting knowledge claims (Bråten et al., 2011; Bråten & Strømsø, 2010; Britt et al., 2014; Schraw, Dunkle, & Bendixen, 1995). In this regard, Bråten et al. (2011) introduced a theoretical framework that specifies how different epistemic belief dimensions influence the understanding of multiple, partly conflicting information sources. Specifically, beliefs in uncertain knowledge are proposed to be beneficial for juxtaposing inconsistent information, whereas beliefs in certain knowledge are assumed to prompt readers to search for a single correct answer. Accordingly, uncertainty beliefs should lead to more in-depth processing when readers are confronted with scientific controversies (Bråten et al., 2011; Bråten et al., 2016).

Professed versus enacted epistemic beliefs

Usually, epistemic beliefs are either assessed with self-report measures such as questionnaires, or they are measured directly in a particular context, for example by using verbal reports (see Mason, 2016 and Sandoval, Greene, & Bråten, 2016, for an overview). In line with these different approaches, several authors have introduced dichotomous terms differentiating between professed and enacted epistemic beliefs (Louca, Elby, Hammer, & Kagey, 2004), espoused beliefs and beliefs in practice (Chai & Khine, 2008), or formal and practical epistemology (Sandoval, 2005), to distinguish the two assessment approaches. In the present study, we built upon Louca et al.'s (2004) terminology of professed and enacted epistemic beliefs, differentiating between *professed uncertainty beliefs* (PUB) and *enacted uncertainty beliefs* (EUB).

In self-report measures that attempt to assess PUB, respondents are asked to rate their agreement with statements about the certainty or uncertainty of knowledge either in general (e.g., Schommer, 1990) or in relation to a particular subject domain such as science (e.g., Conley et al., 2004). However, criticism has been raised that questionnaires provide only decontextualized measures because “what students say about knowledge, science, or experiments in general might have little connection with their actual epistemic practices of reasoning and thinking about real matters” (Sinatra & Chinn, 2012, p. 264, see also Bendixen & Rule, 2004; Greene & Yu, 2014).

EUB are usually measured with verbal data such as cognitive interviews or thinking-aloud (e.g., Ferguson, Bråten, & Strømsø, 2012; Greene, Torney-Purta, Azevedo, & Robertson, 2010; Hofer, 2004; Mason, Ariasi, & Boldrin, 2011; Mason, Boldrin, & Ariasi, 2010a; Muis, Duffy, Trevors, Ranellucci, & Foy, 2014). Whereas cognitive interviews are prone to elicit information that participants will consider only because they were asked the respective questions (Hofer & Sinatra, 2010; Schraw, 2000), thinking-aloud has the advantage of producing information about cognitive processes when individuals complete a task (Mason, Boldrin, & Ariasi, 2010b). Furthermore, van Gog, Paas, van Merriënboer, and Witte (2005) proposed so-called cued retrospective reports as a procedure in which participants are presented with cues of their own task performance (e.g., a video of their own eye movements) as a cue for retrospectively thinking aloud. Compared to concurrent thinking-aloud, this approach can result in more verbal utterances on a cognitive and metacognitive level without altering the quality of participants’ responses (Brand-Gruwel, Kammerer, van Meeuwen, & van Gog, 2017; Hyrskykari, Ovaska, Majaranta, Räihä, & Lehtinen, 2008), and without impairing task performance (Fox, Ericsson, & Best, 2011).

However, rather than assessing either PUB or EUB, in the present paper we propose to measure PUB and EUB in conjunction, as such triangulation of data sources is likely to produce more valuable insights into the construct of uncertainty beliefs and how it relates to the evaluation of scientific controversies than could be gathered by only one data source (Muis, 2007).

Relation between professed and enacted epistemic beliefs

The relation between professed and enacted epistemic beliefs, that is, between what individuals say they think about knowledge and knowing in general and what they actually think in a certain context, has recently been described by Alexander (2016) as one of the big unresolved questions in the field. It has been suggested that individuals’ professed epistemic beliefs can inform their enacted epistemic beliefs in a given context in the sense that “epistemic beliefs are the content upon which epistemic cognition processes act” (Greene, Sandoval, & Bråten, 2016, p. 5). Both PUB and EUB can be adaptive for the evaluation of scientific controversies. With respect to PUB, they have been shown to be beneficial for readers in integrating multiple texts (Strømsø, Bråten, & Samuelstuen, 2008) and in constructing arguments with regard to a controversial topic (Bråten & Strømsø, 2010). Furthermore, an eye-tracking study by Mason and Ariasi (2010) showed that PUB were positively correlated to readers’ fixation times on controversial or ambiguous information. Besides, a study by Richter and Schmid (2010) showed that students with stronger PUB reported more advanced consistency cheking strategies. Finally, a recent meta-analysis revealed that PUB, among other factors, predicted achievement in terms of argumentation and conceptual knowledge (Greene, Cartiff, & Duke, 2018).

Likewise, with respect to EUB, several studies also have provided evidence for a positive relation to individuals’ performance in terms of online learning (Cho, Woodward, & Li, 2018), self-regulation (Richter & Schmid, 2010), and science learning strategies (Lee, Liang, & Tsai, 2016). Yet, to the best of our knowledge, there is only one empirical study by Mason et al. (2010a) that has directly investigated the interplay of PUB and EUB. The authors examined 8th grade students’ Web search behavior on a controversial topic and found that PUB were related to EUB during an online search task as measured by retrospective interviews (i.e., by the question „How stable over time do you think the information you found on the Internet is?“). However, EUB were not significantly related to the learning outcome, neither were such relations for PUB reported in this study.

The present study

The aim of the present study was to investigate the relation between PUB and EUB and their role in university students’ evaluation of scientific controversies. Drawing on prior research, we defined PUB as individuals’ self-reported beliefs about the uncertainty of science-related knowledge and EUB as individuals’ verbalized beliefs about the uncertainty of knowledge related to their task processing, that is, the evaluation of scientific controversies. We focused on university students in the present study because scientific controversies both play a central role in their academic careers (Sinatra & Chinn, 2012) and become increasingly important for young adults’ personal life decisions (Bromme & Goldman, 2014; Feinstein, 2011; Greene & Yu, 2016). Based on the assumption that professed and enacted uncertainty beliefs are interrelated in the sense that individuals activate the beliefs they hold in the context for which these beliefs are adaptive (Bråten et al., 2016; Sandoval et al., 2016), we expected a positive correlation between PUB and EUB (Hypothesis 1).

Furthermore, we tested the respective relations of both PUB and EUB with individuals' performance when evaluating scientific controversies. Based on previous findings (e.g., Greene, Cartiff et al., 2018 for PUB, or Cho et al., 2018 for EUB) we hypothesized that individuals' evaluation of scientific controversies would be predicted by both PUB (Hypothesis 2) and EUB (Hypothesis 3). Moreover, we expected that due to their close link to individuals' actual cognition (Barzilai & Zohar, 2014), the effect of EUB on controversy-evaluation performance would be larger than the effect of PUB (Hypothesis 4).

Finally, building on our prior hypotheses, we predicted that the positive relation between PUB and controversy-evaluation performance would be mediated by EUB (Hypothesis 5). The enactment of uncertainty beliefs, which implies this mediation effect, has been proposed by different theoretical models. Several authors have suggested that underlying epistemic beliefs would influence performance through adaptive epistemic cognitive processes (Bråten et al., 2016; Hofer, 2001; Muis, 2007). Thus, in the present study, we analyzed whether this prediction would hold for uncertainty beliefs when university students evaluated scientific controversies.

Method

Participants

Participants were N = 83 university students. Data from four students had to be excluded due to technical problems or because they did not complete the study. Thus, all analyses were conducted with N = 79 students (mean age = 20.8 years; SD = 2.08; 70% female). The study took place at a large German university with participants from different majors (45 from the natural sciences, 20 from the social sciences and humanities, 7 from economics and business, 7 from psychology and cognitive science). They received 12 € for their participation. German was the first language of all participants. The study was approved in advance by the local ethics committee, and participants gave their written consent at the beginning of the study.

Materials

Controversy-evaluation test. The dependent measure was students' performance in evaluating scientific controversies. This was measured with a controversy-evaluation test that required the evaluation of five texts that each described a scientific controversy between two scientists and respective claims regarding central aspects of the controversy (Kramer, Oschatz, Wagner, Thomm, & Bromme, 2019). The controversy-evaluation test was an element from the National Education Panel Study (NEPS; Oschatz, Kramer, & Wagner, 2017), and had the aim of assessing the ability to critically reflect on opposing scientific claims as an indicator of individuals' ability to evaluate scientific controversies. Because the controversy-evaluation test was initially developed for high school students (i.e., Grades 12 and 13[3]), the difficulty of the test was assumed to be appropriate for our sample of undergraduate students. Each of the five texts included a vignette describing a scientific controversy regarding a scientific debate. Table 4.1 provides an overview of the titles, content, and length of the five scientific controversies. As can be seen from the titles, the controversy-evaluation test covered a range of different topics within the domain of science. Each of the controversies was presented on one page (M = 349.6 words, SD = 52.68), containing a short introduction to the topic followed by a description of the opposing perspectives of two fictitious scientists on the respective issue. Each controversy was accompanied by five to seven statements about possible reasons for the controversy or the conflicting claims. Participants were asked to judge these statements as correct or incorrect.

For example, in the "Chemical plant" controversy, two chemists presented soil samples from varying distances to a chemical plant, resulting in contradictory claims as to whether the emissions were harmful. One of the chemists stressed that children playing close to the chemical plant would be in particular danger. One statement relating to this controversy was "The

Table 4.1

Description of the scientific controversies from the controversy-evaluation test

Title of the controversy	***Content***	***Number of words***	***Number of items***
Nervous dogs	Two scientists argue about whether nervousness in dogs is best treated with behavioral training or medication.	369	5
Epigenetics	Two scientists argue about whether or not environmental influences can change DNA.	376	7
Marathon training	Two scientists argue about the effectiveness of a certain kind of marathon training.	273	6
Chemical plant	Two scientists argue about whether or not the emissions from a chemical plant are harmful.	309	7
Preimplantation diagnostics	Two scientists argue about the scientific and ethical aspects of genetic testing prior to implanting embryos.	410	7

[3] In Germany, the academic track of upper secondary school lasts until Grade 12 or Grade 13

argumentation of Scientist A would also be plausible if he didn't refer to playing children." For a correct answer, participants had to recognize that, in this case, a reference to playing children did not convey a valid argumentation by itself. Therefore, the correct answer to this statement was "yes" because the plausibility of the arguments underlying the example was not affected by a reference to playing children. Another item addressing this controversy is "Because scientist B wants to demonstrate the harmlessness of the chemical plant, it is scientifically correct that he publishes only the matching results". Based on different results presented by the two chemists, participants need to identify the underlying cause that the collection and presentation of scientific data should not be determined by desired results. Therefore, the right answer to this item is "incorrect". Items were carefully designed so that they could be solved by interested laypeople and did not require prior knowledge of the underlying topics. Instead, the goal was to measure individuals' critical reflection about opposing scientific claims regarding theoretical, methodological, and ethical aspects, with high scores indicating a more proficient evaluation of scientific controversies. Such critical reflection is distinct from individuals' uncertainty beliefs (Thomm, Barzilai, & Bromme, 2017). Rather, the latter can be seen as a prerequisite for adequately coping with the former. In total, the controversy-evaluation test consisted of 32 items and yielded an acceptable reliability of $\alpha = .66$ in the present study.

Professed uncertainty beliefs. To measure participants' professed (i.e., self-reported) uncertainty beliefs in the domain of science, we used two subscales from the Scientific Epistemological Beliefs Questionnaire developed by Conley et al. (2004). These subscales are labeled certainty of science-related knowledge (six items, e.g., "Scientists always agree about what is true in science") and development of science-related knowledge (six items, e.g., "Ideas in science sometimes change"). Following Mason, Gava, and Boldrin (2008), we collapsed these two subscales into one scale in order to achieve a conceptual correspondence with the original measurement of uncertainty beliefs by Hofer and Pintrich (1997), which contains both aspects (i.e., uncertainty and development of knowledge). Items from the certainty subscale were recoded so that high values for all items of the scale indicated beliefs about uncertain (i.e., tentative and evolving) knowledge. The resulting scale consisted of 12 items that were answered on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree), with an acceptable reliability of $\alpha = .75$.

Enacted uncertainty beliefs. We used cued retrospective verbal reports (van Gog et al., 2005) to measure participants' enacted uncertainty beliefs, that is, their epistemic cognitive processes while they were working on the controversy-evaluation test. In this procedure, participants retrospectively verbalize their thought processes when working on a task, prompted by their eye movements shown to them as cues. To obtain these cues, we used an SMI (Senso Motoric Instruments) remote eye-tracker to record participants' eye movements as they looked at the computer screen to complete the controversy-evaluation test. After participants had completed the task, for each controversy we played their own test-taking behavior back to them at 50% speed (Kammerer, Bråten, Gerjets, & Strømsø, 2013; van Gog et al., 2005) as a so-called gaze replay, a screen-recording video with their eye movements superimposed. We only confronted participants with the parts of the gaze replay that showed how they answered the items. That is, we presented participants with indicators of their covert cognitive processes (i.e., their own eye movements, depicted as a yellow dot representing participants' fixation points) as well as their overt actions (i.e., mouse movements and clicks; van Gog & Jarodzka, 2013; van Gog, Kester, Nievelstein, Giesbers, & Paas, 2009) while they answered the items on the controversy-evaluation test.

Before watching the gaze replay, participants received the following instructions for the verbalization (that were in line with the standards described by Ericsson & Simon, 1993): *"In the following, you will be shown a video with a recording of your eye movements when answering the questions. Please watch the video and tell me everything you were thinking then. In the video, you will see a yellow dot that moves across the screen. This is the recording of your eye movements. The video will be played at half speed so that you have the opportunity to comment on your eye movements. Just act as though you were alone in the room talking to yourself. It is important that you verbalize everything that comes to mind. This is not about your thoughts being correctly formulated or thought through. If you don't say anything for a while, I will ask you to speak. I will play the video now and start a new recording that records what you are saying. Please keep in mind that you should verbalize everything you were thinking about when answering the questions."*

Coding of the verbal protocols. Participants' verbalizations during cued retrospective reporting were audiotaped and transcribed. Transcripts were then segmented into idea units that comprised a coherent statement. Note that idea units can consist of only a few words up to several sentences, depending on the semantic structure of what participants expressed rather than grammatical considerations. In order to identify idea units that referred to uncertainty beliefs in the verbal protocols, a coding scheme was developed in a deductive process, taking into account the theoretical framework of the study as well as the context of test-taking when participants completed the controversy-evaluation test (see Table 4.2). Because the idea units produced by participants were based on their reflections about how they answered the items rather than directly addressing their uncertainty beliefs, two steps had to be fulfilled for an idea

Table 4.2

Coding scheme and interrater agreement for the verbal protocols

Category	Description of category	Krippendorff's α (based on a 20% subsample)
Step 1		
Content	Refers to the content of the scientific controversy (e.g., evaluation or juxtaposition of the different viewpoints)	.90
Test-taking process	Refers to the process of test-taking (e.g., description of reading behavior)	.90
Step 2		
Uncertain knowledge	Enacts beliefs in uncertain (i.e., tentative and evolving) knowledge	.81
Certain knowledge	Enacts beliefs in certain (i.e., absolute and fixed) knowledge	.80
Other	Refers to other content-related aspects (e.g., repeating or summarizing content, relevance of the topic, prior knowledge)	.85
Total idea units	–	.84

unit to be coded as referring to uncertain or certain knowledge. In Step 1, idea units were coded with respect to whether they referred to (a) the content of the respective controversy or to (b) participants' actions during the test-taking process (e.g., "Now I'm reading the next question"). If an idea unit was coded as referring to content, the decision in Step 2 was whether, in an epistemic sense, the idea unit referred to (a) uncertain knowledge (e.g., "I don't think that new views or findings should be valued less than old ones", or "It is hard to say whether such statements are correct, because in my opinion several views can be correct. And they can be more or less substantiated, and there are models that sometimes apply and sometimes they don't"), (b) certain knowledge (e.g., "No, I mean evolutionary biology is just as up-to-date as it was then. That doesn't make a difference, nothing is changing"), or (c) other content-related aspects such as personal relevance, summarizing content, or methodological aspects (e.g., "After reading the controversy, I thought it's always good to have a control group"). As can be seen from these examples, when coding for beliefs about the uncertainty or certainty of knowledge, the idea units were carefully examined for whether or not they suggested that scientific knowledge is complex and subject to change and whether or not they acknowledged disagreement between the two scientists.

Two raters familiar with the task coded a random sample of 20% of the verbal protocols, that is, participants' idea units for all five controversies. Interrater agreement was acceptable with Krippendorff's α = .84 for all codes, ranging from α = .80 for "certain knowledge" to α = .90

for the “content” and the “test-taking process” (see Table 4.2). All disagreements between the two raters were resolved through careful discussion. After consensus was achieved, one rater coded the remaining verbal protocols.

Control variables. Because of the text-intensive nature of our assessment as well as prior research linking the belief that knowledge is certain to poor reading skills (Cho et al., 2018), we used reading comprehension ability as a covariate. This was measured with a standardized German cloze test (LGVT 6-12 by Schneider, Schlagmüller, & Ennemoser, 2007). On this test, participants are given 4 min to underline up to 23 target words that are presented next to two false words. They receive 2 points for every correctly underlined word, -1 point for every incorrectly underlined word, and 0 points if no word was underlined, resulting in a reading comprehension score ranging from -23 to +46.

Moreover, as a result of the data collection procedure, the length of the gaze replay we showed to participants to collect cued retrospective verbal reports varied depending on how long it took participants to answer the items. Hence, to account for the time available for verbalization during cued retrospective reports, we controlled for gaze replay duration.

Procedure

We measured PUB approximately 1 week before the lab sessions with an online questionnaire in order to avoid carryover effects to the subsequent assessment of EUB. Then, participants were tested in single sessions in the lab. The five scientific controversies from the controversy-evaluation test and their accompanying items were each presented successively on a single page on a computer screen, and the items were answered via a mouse click. Calibration to the eye-tracking system was repeated before each controversy to increase measurement accuracy. After participants completed the controversy-evaluation test, we showed them the gaze replay of their test-taking performance for all five controversies in the original order and recorded their cued retrospective verbal reports. Hence, whereas the resulting score on the controversy-evaluation test served as a measure of participants’ controversy-evaluation performance, their utterances during test-taking as measured with the cued retrospective reports were used as online measures of EUB. Finally, we assessed their reading comprehension ability.

Results

Descriptive Results and Intercorrelations

Table 4.3 provides an overview of the descriptive and correlational results. On average, gaze replay duration was 1,205.71 s (*SD* = 314.74), and we coded an average of 49.19 (*SD* = 13.12) idea units per participant in the verbal protocols. About two-thirds of the idea units were related to the content of the controversies (*M* = 32.77, *SD* = 11.10) and one-third to participants' test-taking process (*M* = 16.42, *SD* = 14.47). Among the content-related idea units, beliefs in uncertain knowledge (i.e., EUB) were coded *M* = 2.46 times (*SD* = 2.24), and beliefs in certain knowledge were coded *M* = 0.32 times (*SD* = 0.69) per participant. Due to the low frequency of the latter (only 16 out of the 79 participants uttered at least one idea unit related to certain knowledge), as in Mason et al. (2010a) this category was excluded from further analyses. Reading comprehension ability was negatively correlated with gaze replay duration ($r = -.29$, $p = .010$). However, because reading comprehension ability was not significantly related to any other measure, it was not considered in further analyses. In the following, we present the results of our hypothesis-testing. In the results of the multivariate analyses, we report standardized coefficients to allow for easier interpretation.

Hypotheses 1, 2, 3, and 4: Interrelations of PUB, EUB, and controversy-evaluation performance

In Hypothesis 1, we predicted that PUB and EUB would be interrelated. As shown in Table 4.3, there was a small but significant correlation between these variables ($r = .23$, $p = .045$), confirming our prediction. We also found support for Hypotheses 2 and 3, which predicted a positive correlation between controversy-evaluation performance and PUB ($r = .45$, $p < .001$) and between controversy-evaluation performance and EUB ($r = .33$, $p = .003$). However, we also found significant correlations between EUB and gaze replay duration ($r = .36$, $p = .001$) and between EUB and number of idea units related to the test-taking process ($r = -.40$, $p < .001$). Number of idea units related to test-taking process also showed a significant negative correlation with controversy-evaluation performance ($r = -.29$, $p = .010$). To investigate whether these variables would alter the relation between EUB and performance in the controversy-evaluation test, we conducted a multiple linear regression analysis. We used controversy-evaluation performance as the dependent variable and EUB, gaze replay duration, and idea units related to the test-taking process as predictor variables. In the resulting model, $R^2 = .14$, $F(3, 75) = 4.09$, $p = .010$, neither of the two control variables significantly predicted

Table 4.3

Summary of intercorrelations and descriptive statistics for all measured variables

Variable	1	2	3	4	5	6	*M*	*SD*	*Min*	*Max*	*Skewness*	*Kurtosis*
1. Controversy-evaluation performance	—						24.41	3.73	15	32	-0.34	-0.33
2. Professed uncertainty beliefs	.45***	—					4.35	0.36	3.08	5.00	-0.82	1.14
3. Enacted uncertainty beliefs (# of idea units)	.33**	.23*	—				2.47	2.24	0	9	1.07	1.12
4. Test-taking process (# of idea units)	-.29*	-.12	-.40***	—			16.42	14.47	0	66	1.61	2.46
5. Total # of idea units	-.08	.21	.01	.68***	—		49.19	13.12	25	93	0.64	0.58
6. Gaze replay duration in sec	.07	.08	.36**	-.04	.27*	—	1205.71	314.74	697	2201	0.97	0.74
7. Reading comprehension ability	.13	.19	-.09	-.09	-.16	-.29*	20.42	7.01	1	40	-0.01	0.60

Note. $N = 79$.
*$p < .05$. **$p < .01$. ***$p < .001$.

performance on the controversy-evaluation test (β = -0.18, p = .132 for idea units related to the test-taking process and β = -0.04, p = .762 for gaze replay duration), whereas EUB still showed a positive effect on controversy-evaluation performance (β = 0.27, p = .034). With Hypothesis 4, we predicted that performance in the controversy-evaluation test would be more strongly related to EUB than PUB. On a descriptive level, we found that the correlation between PUB and controversy-evaluation performance was higher than the correlation between EUB and controversy-evaluation performance. However, this difference was not significant (z = -1.81, p = .07). Thus, Hypothesis 4 was not supported, and there was even a tendency toward the opposite pattern, that is, a stronger association between PUB and participants' performance in the controversy-evaluation test.

Hypothesis 5: Mediating role of EUB

Finally, we tested Hypothesis 5, which proposed that the positive relation between PUB and performance in the controversy-evaluation test would be mediated by EUB. According to the classic work of Baron and Kenny (1986), the prerequisites for a mediation model were met: There was a positive correlation between the predictor and mediator (i.e., PUB and EUB), between the mediator and dependent variable (i.e., EUB and controversy-evaluation performance), and between the predictor and dependent variable (i.e., PUB and controversy-evaluation performance; see Table 4.3). The fourth prerequisite is that, when controlling for the mediator, the effect of the predictor decreases (partial mediation) or vanishes (complete mediation). Modern bootstrapping-based techniques additionally allow for significance testing when investigating an indirect effect (Hayes, 2013). Thus, we tested for an indirect effect of PUB on performance in the controversy-evaluation test through EUB as shown in Figure 4.1 with a preset number of 10,000 bootstraps. When including EUB as a mediator, we found that

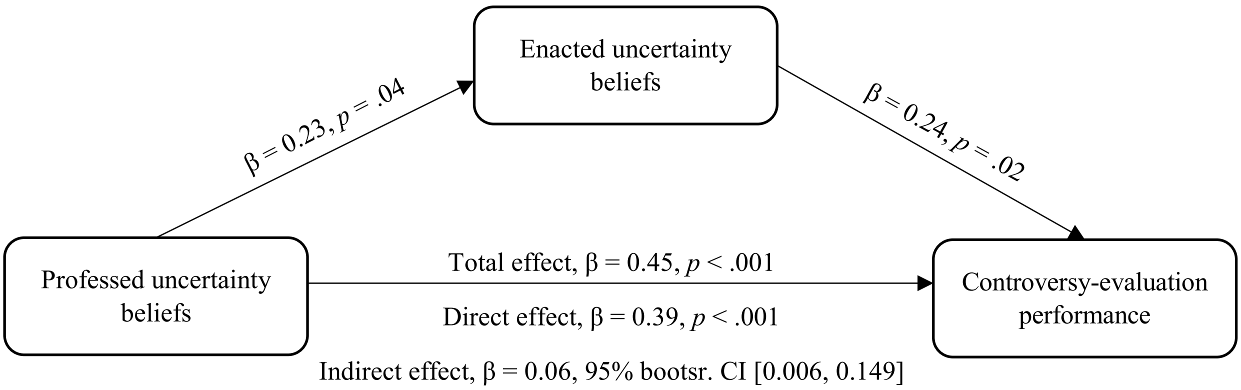

Figure 4.1 *Mediation of professed uncertainty beliefs on controversy-evaluation performance through enacted uncertainty beliefs*

there was still a strong association between PUB and performance in the controversy-evaluation test ($\beta = 0.39$, *SE* = .120, $p < .001$). However, there was also a significant indirect effect of PUB on controversy-evaluation performance through EUB ($\beta = 0.06$, 95% bootstrapped CI [0.006, 0.149]), indicating a partial mediation.

Discussion

Summary of Empirical Findings

In this study, we investigated the relation between PUB and EUB as well as the relevance of these variables in the evaluation of scientific controversies. We found evidence for a small but significant correlation between PUB and EUB (Hypothesis 1). This implies that, as expected, individuals' general perceptions of the uncertainty of science-related knowledge are related to the ways in which they reflect on the uncertainty of knowledge in the context of evaluating scientific controversies. Note that, in line with previous research (Mason et al., 2010a), we found that participants expressed mainly beliefs in uncertain knowledge, but not in certain knowledge, in their verbalizations. Furthermore, both PUB and EUB predicted performance on the controversy-evaluation test (Hypotheses 2 and 3). In Hypothesis 4, we predicted that EUB would be more closely linked to participants' controversy-evaluation performance than PUB would be (cf. Barzilai & Zohar, 2014). This hypothesis was not confirmed, and the relation between performance in the controversy-evaluation test and PUB tended to be even stronger than the respective relation with EUB. Finally, in line with Hypothesis 5, EUB were found to partially mediate the relation between PUB and students' performance on the controversy-evaluation test. The enactment of underlying uncertainty beliefs in a given context, as it has been assumed in the literature (e.g., Hofer, 2001; Muis, Trevors, & Chevrier, 2016), is reflected in this mediation model. However, it should be noted that the mediation effect was small and the remaining effect of PUB on the controversy-evaluation test performance was substantially larger than the effect of the mediator EUB. Moreover, due to the correlational data structure, these results should not be interpreted as causal effects.

Theoretical Implications

Our results provide novel theoretical insights into the relations between professed and enacted beliefs about the uncertainty of science-related knowledge and their role in individuals' evaluation of scientific controversies. Whereas prior research has focused on either professed or enacted uncertainty beliefs (see also Sandoval et al., 2016), our study suggests that a direct juxtaposition of the two conceptualizations will yield more theoretical clarification as to how individuals evaluate conflicting information.

Specifically, we found that on a descriptive level, the relation between PUB (i.e., the decontextualized measure of science-related uncertainty beliefs) and controversy-evaluation test performance was larger than that of EUB. It appears that epistemic beliefs are not an entirely contextualized phenomenon, but rather that PUB and EUB are different facets of the same construct. Whereas PUB as measured with a questionnaire might represent participants' explicit and more general beliefs about the uncertainty of science-related knowledge, EUB as measured by cued retrospective verbal reports probably reflect more tacit and context-specific beliefs. A potential post hoc explanation for the stronger association between PUB and performance in the controversy-evaluation test is that in both of these measures, participants were asked to explicitly state their agreement with different written claims, as compared with the open-ended, oral format of the cued retrospective verbal reports. Moreover, correlations of this magnitude are typical when comparing offline measures such as questionnaires and online measures such as verbal reports (e.g., Cromley & Azevedo, 2007). The different assessment modalities might also, at least in part, account for the smaller effect of the mediator EUB on the test score in comparison with the large effect of PUB, because PUB and the controversy-evaluation test drew on similar data sources. Another possible explanation for the relatively small relation between EUB and individuals' performance in the controversy-evaluation test is related to task demands of cued retrospective verbal reports. This method may have been uncomfortable for some participants or may have exceeded their cognitive capacities (Chinn et al., 2011; Schraw, 2000). The negative correlation between the number of idea units related to the test-taking process with participants' controversy-evaluation performance indicates that the verbalization task might have been too demanding for some participants to reflect on the scientific controversies beyond a merely descriptive level. This conclusion needs to remain speculative, however, and more research is needed to clarify how the cognitive demands of a task influence the quality of verbal protocols (Jarodzka & Boshuizen, 2017).

Furthermore, PUB and EUB also correlated only moderately. The theory of integrated domains in epistemology (TIDE; Muis, Bendixen, & Haerle, 2006) offers a potential explanation for this result. According to the TIDE, epistemic beliefs operate on different levels, from general to specific, with a reciprocal relation between these different levels of epistemic beliefs (see also Merk, Rosman, Muis, Kelava, & Bohl, 2018). In the present study, we measured PUB in the domain of science, while the EUB measure rather reflects participants' science-related beliefs on a topic-specific level (across 5 different scientific issues). Whereas

PUB are assumed to be relatively stable, EUB partly depend also on the context of the respective topic in which they are enacted, which is why a one-to-one correspondence between PUB and EUB is unlikely (cf. Muis et al., 2006). Future research could examine PUB also on a topic-specific level (cf. Mason et al., 2010a). However, in the context of our research this would mean to assess PUB for the five different topics separately.

Whereas prior research on epistemic beliefs has primarily relied on either analyses of verbal data (often using small samples) or quantitative assessments of questionnaires, a strength of the present study is the integration of the two approaches. Hence, the present study provides an example of how different conceptualizations of an epistemic belief dimension can translate into respective measurement approaches, aligning the employed measurements with the constructs in question (cf. Barzilai & Zohar, 2014; Mason et al., 2010a; Sandoval et al., 2016). Given that both PUB and EUB were able to explain variance in the performance of the controversy-evaluation test, we argue that EUB should not be conceptualized as entirely dependent on context, nor are PUB likely to fully determine how individuals think about—in this case—scientific controversies. Rather than striving for a true or direct measurement of uncertainty beliefs, both explicit and tacit measures seem necessary for understanding how individuals evaluate conflicting scientific information (Limón, 2006; Sandoval & Millwood, 2007). Whereas PUB might serve as an underlying mindset that affects, for instance, which tasks individuals select, EUB have the added value of explaining the epistemic cognitive processes that occur when individuals are engaged in such tasks (Hofer, 2004; Muis, 2007; Pieschl, Stallmann, & Bromme, 2014).

Practical Implications

We now outline some key practical implications of the present study for science instruction, in particular when it comes to instruction at the university level. Our finding that both PUB and EUB are important for individuals in dealing with scientific controversies suggests that both of these facets should be an integral part of science curricula. To explicitly teach the epistemic underpinnings of a particular subject and also have students engage in epistemic practices will likely advance both their professed and enacted beliefs about the uncertainty of science-related knowledge inside as well as outside an academic setting, for example, when they are searching the Internet for science-related information (Strømsø & Kammerer, 2016). Borrowing from Veenman, van Hout-Wolters, and Afflerbach's (2006) principles of metacognitive instruction, educators might be advised to (a) connect the content matter to instruction about the uncertainty of knowledge (e.g., introduce multiple, conflicting viewpoints on a biological theory), (b) explain to students the usefulness of enacting their uncertainty beliefs for solving the task (e.g., the solution might lie in an integration of the different viewpoints), and (c) have students apply these skills repeatedly in order to internalize the critical evaluation of the uncertainty of knowledge (e.g., confront them with opposing or changing viewpoints in different topics or domains). Zohar and Barzilai (2013) concluded that this kind of metacognitive instruction, in which students' ways of thinking about knowledge and knowing are made salient, can best advance the epistemic understanding of science.

We believe that the alignment of PUB and EUB will have an impact not only on students' understanding of science but also on other academic and nonacademic areas (cf. Sandoval, 2005). Having access to one's beliefs about the uncertainty of science-related knowledge and knowing when and how to apply them will likely help individuals in our modern knowledge-based society draw more valid conclusions from competing knowledge claims pertaining to science-related topics of personal relevance, allowing them to make more informed decisions (Feinstein, 2011; Roth & Lee, 2004; Yang & Tsai, 2010).

Limitations and Future Directions

The present study is one of the first attempts to provide a joint empirical, quantitative examination of professed and enacted epistemic beliefs about the uncertainty of science-related knowledge and their mediational relationship in the context of evaluating scientific controversies. Bearing this in mind, the study is not without its limitations, but it also points toward promising possibilities for future research.

One limitation of the present study is that due to the correlational data structure, we cannot draw firm conclusions about causal mechanisms with respect to PUB, EUB, and the evaluation of scientific controversies. Whereas we tested the prediction of the enactment of uncertainty beliefs when evaluating scientific controversies, there is also evidence that, conversely, being confronted with contradictory information can have an impact on individuals' professed epistemic beliefs (Barzilai & Zohar, 2016; Flemming, Feinkohl, Cress, & Kimmerle, 2017; Kienhues, Ferguson, & Stahl, 2016). Similarly, other potential confounding variables that we did not account for in this study (e.g., general cognitive ability) might, in part, provide alternative explanations for our results. Future studies should clarify these questions by using experimental designs with repeated measurements of PUB, EUB, and potential moderators.

Moreover, beliefs in uncertain knowledge are not adaptive in each instance. For example, a study by Lee et al. (2016) found that students who believed in uncertain knowledge showed less deep learning strategies in biology. Indeed, it does not seem beneficial to question the certainty of scientific knowledge for phenomena on which there is broad consensus (e.g., “The earth is round.”, see also Sinatra et al., 2014). Presumably, as the ambiguity and complexity of scientific issues increase, so does the relevance of uncertainty beliefs in explaining the different opposing viewpoints. It is therefore plausible to assume that uncertainty beliefs are beneficial for the evaluation of scientific controversies, but caution is warranted to overgeneralize the adaptiveness of uncertainty beliefs to other contexts or tasks.

Finally, given the complexity of the research question, we chose to focus our analyses on a specific epistemic belief dimension in a particular context using a relatively homogeneous sample of university students. This narrow focus came along with certain restrictions in terms of generalizability. Future research might investigate the adaptiveness of uncertainty beliefs in different contexts and with different age groups or educational backgrounds (Greene & Yu, 2014). For example, individuals might apply their uncertainty beliefs differently in conditions that are less standardized than our controversy-evaluation task, such as a free Web search (Greene, Copeland, Deekens, & Yu, 2018; Greene, Yu, & Copeland, 2014; Kammerer et al., 2013; Mason et al., 2010a; Mason et al., 2011). Furthermore, participants without a university background might differ in their uncertainty beliefs or might apply them differently (cf. Kammerer, Amann, & Gerjets, 2015). Moreover, we recommend that future studies aim to identify other individual or situational factors that contribute to the enactment of uncertainty beliefs when individuals evaluate conflicting scientific information, such as individuals’ cognitive engagement (Ravindran, Greene, & DeBacker, 2005) or the nature of the task (e.g., summary tasks versus argument tasks, see Gil, Bråten, Vidal-Abarca, & Strømsø, 2010). In addition, future studies should investigate whether our findings can be replicated for other epistemic belief dimensions, bearing in mind that different dimensions of epistemic beliefs might be adaptive for different kinds of tasks (Sandoval et al., 2016). We argue that instead of obliterating the seemingly outdated construct of (professed) epistemic beliefs, it might in fact be a more promising approach to clearly state the conceptual overlap and differences between professed and enacted epistemic beliefs (Alexander, 2016; Hofer, 2016).

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5

General Discussion

5 General Discussion

In our modern-day knowledge society, competing scientific knowledge claims are proliferating (Bromme et al., 2018; Goldman & Scardamalia, 2013). Hence, if individuals want to make use of scientific information for their everyday life decisions, they must be able to critically evaluate scientific controversies in order assess the veracity of these competing knowledge claims (Britt et al., 2014; Carey & Smith, 1993; Sandoval, 2005; Sinatra et al., 2014). The studies in the present dissertation investigated and integrated two central constructs that can be beneficial for the evaluation of scientific controversies: first, individuals' uncertainty beliefs, that is, their epistemic beliefs as to how certain or uncertain they judge knowledge to be and second, individuals' cognitive engagement, that is, the amount of psychological effort invested when dealing with scientific information. The contribution to research made by the present dissertation is twofold. On the one hand, it broadens the conceptual understanding of how individuals address scientific controversies by integrating research on epistemic beliefs and engagement (Study 1). On the other hand, it provides a deeper understanding of the respective constructs by investigating different manifestations of cognitive engagement (Study 2) and uncertainty beliefs (Study 3). The following section provides an overall summary of the three studies, situating the findings in a broader research context (see 5.1). Further, strengths and limitations (see 5.2) as well as the implications for future research and practice (see 5.3) will be discussed.

5.1 Discussion of General Findings

5.1.1 A broader understanding of uncertainty beliefs and cognitive engagement

The present dissertation builds upon the theoretical assumption of an association between uncertainty beliefs and cognitive engagement when individuals evaluate scientific controversies. In the following, the rationale behind this assumption as well as the empirical contribution of the present dissertation will be discussed from a broader perspective.

Next to other epistemic belief dimensions, uncertainty beliefs constitute a set of relatively stable beliefs regarding knowledge and knowing. Uncertainty beliefs are related to the nature of knowing, and individuals who hold strong uncertainty beliefs consider knowledge to be tentative and evolving rather than absolute and fixed (Hofer & Pintrich, 1997). There is ample theoretical and empirical work indicating that the belief that knowledge is uncertain is beneficial for the evaluation of controversial information (e.g., Bråten et al., 2011; Kardash & Scholes, 1996; Mason et al., 2010a). However, evaluating controversial information is a complex task, and little is known about the processes of how uncertainty beliefs can contribute to a proficient evaluation of contradictory knowledge claims (Bråten et al., 2011; Bråten et al., 2016). It has been assumed that the effortful processing of information (i.e., cognitive engagement) is a result of uncertainty beliefs (Hofer, 2004b; Sinatra, 2016). In turn, cognitive engagement has been defined in the present dissertation as the effortful allocation of mental resources during a certain task. In this sense, high cognitive engagement alone will not suffice to solve a complex task such as evaluating scientific controversies. Rather, other more distal variables that guide a reader's actual cognitive engagement during the evaluation process have to be considered (DeBacker et al., 2008; Renninger et al., 2018). Similarly, Pintrich and Schrauben (1992) referred to cognitive engagement as a "skill" component, which has to be activated through "will" components in order to guide individuals' cognition. Taken together, uncertainty beliefs might stimulate individuals' will to engage deeply with controversial information. The finding from Study 1 that cognitive engagement partly mediated the effect of uncertainty beliefs on the evaluation of scientific controversies supported the abovementioned assumptions. Participants holding strong uncertainty beliefs also showed stronger cognitive engagement, which in turn was associated with more proficient evaluation.

This result addresses propositions put forward by both epistemic belief and engagement research, thereby integrating these research traditions (see 1.3.2). From a broader perspective, uncertainty beliefs can serve as a cognitive schema against which conflicting scientific information is inspected (Chinn, Rinehart, & Buckland, 2014; Muis, Trevors, & Chevrier, 2016). Advanced beliefs that acknowledge uncertainty and contradictions should therefore be prerequisites to making cognitive engagement meaningful. In line with the general framework of the present dissertation (see Table 1.2), Study 1 investigated the relation between professed uncertainty beliefs and situational cognitive engagement. Studies 2 and 3 differentiated between additional manifestations within the respective constructs, as will be outlined below.

5.1.2 A deeper understanding of cognitive engagement

Cognitive engagement is a popular construct in educational science that has been linked to favorable student outcomes such as persistence and achievement (Fredricks et al., 2004; Kuh et al., 2008; Pietarinen et al., 2014). However, the lack of theoretical consensus in engagement research, especially in the domain of science, threatens the usefulness of the construct (Azevedo, 2015; Reschly & Christenson, 2012; Sinatra et al., 2015). The present dissertation makes the point that only by differentiating cognitive engagement from other constructs such as motivation can the contribution of cognitive engagement in individuals' cognition truly be estimated. On the other hand, confounding it with other variables that are relevant in the learning process diminishes the explanatory power of the cognitive engagement construct. Moreover, whereas the major part of engagement research has investigated multiple engagement dimensions using only one indicator, the present dissertation pursued an in-depth analysis of cognitive engagement by integrating multiple indicators from the literature. A traditional self-report measure of general cognitive engagement (Wang et al., 2016) was complemented by indicators of situational cognitive engagement (i.e., mental effort during task processing), both in terms of self-reported indicators (Paas, 1992) and process-related indicators such as pupil dilation (e.g., van der Wel & van Steenbergen, 2018). The interrelation of these different indicators was the specific focus of Study 2. One of the most noteworthy findings was that the different cognitive engagement measures were hardly correlated. This pointed toward a weak spot in engagement research. Different indicators have commonly been used to measure what is supposed to be the same construct. Whereas it is beyond the scope of the present dissertation to develop an irrefutable and unambiguous approach to measuring cognitive engagement, it showcases the idea that different manifestations of the construct need to be considered and that each of these manifestations needs to be embedded in an appropriate theoretical framework and measured with suitable indicators (Boekaerts, 2016). In other words, Study 2 showed that the level of granularity with which cognitive engagement is being measured, as well as the level of individual awareness, influences the meaning of the construct (Azevedo, 2015; Eccles, 2016). Does the lack of correlation between general and situational cognitive engagement mean that the two are conceptually different? One possible explanation is that the alignment between general and situational cognitive engagement is determined by contextual demands. It is possible that factors such as the familiarity of the task or the artificiality of the lab setting prevented participants from building on their general cognitive engagement during data collection. Another explanation is that general and situational cognitive engagement have a distinct influence on the ways in which individuals approach a task. This assumption was substantiated by the finding that general and situational cognitive engagement are differentially related to control variables such as interest and reading comprehension ability. Whereas general cognitive engagement was able the explain distal aspects such as participants' science interest and their performance on the controversy-evaluation test, situational engagement was correlated with reading comprehension ability, which is a more proximal factor relevant for individuals' cognitive processing during the evaluation of scientific controversies. A comparison of different measures across different contexts might provide more insights into the alignment of general and situational cognitive engagement. In this regard, Study 2 hinted at important definitional and empirical issues for future research on cognitive engagement in the context of evaluating scientific controversies.

5.1.3 A deeper understanding of uncertainty beliefs

As outlined above (see 5.1.1), uncertainty beliefs influence how individuals evaluate, juxtapose, and integrate conflicting information (e.g., Bråten et al., 2011; Mason et al., 2010a). However, past research has largely neglected the differentiation between professed and enacted epistemic beliefs (Alexander, 2016). Regarding uncertainty beliefs, the question that arises is whether and how individuals' professed (i.e., self-stated and general) uncertainty beliefs impact their enacted (i.e., activated and situational) uncertainty beliefs (see 1.1.2). Will individuals who state that knowledge is tentative and evolving (i.e., those who hold strong professed uncertainty beliefs) also show strong enacted uncertainty beliefs during a task in which these beliefs are called upon, such as the evaluation of scientific controversies? To answer this question, different theoretical assumptions regarding individuals' beliefs about the uncertainty of knowledge have to be integrated. This meta-meta-perspective was recently discussed by Sinatra (2016) in a commentary titled "Thoughts on knowledge about thinking about knowledge" in which she argued for more careful construct definitions (see also Greene, Azevedo, & Torney-Purta, 2008). Study 3 of the present dissertation is a step toward more conceptual clarity regarding individuals' professed and enacted uncertainty beliefs. Not only do the findings from Study 3 suggest that professed and enacted uncertainty beliefs are related, it was also shown that enacted uncertainty beliefs partly mediate the relation between professed uncertainty beliefs and participants' performance on the controversy-evaluation test. These findings contradict the assumption of the epistemological resources approach (e.g., Elby & Hammer, 2010) that the beliefs individuals enact in a given task are not based on their general, professed epistemic beliefs but on characteristics of the context. Rather, the findings support a generative approach to epistemic cognition (Kienhues et al., 2016), which implies enacted uncertainty beliefs indeed have a context-specific nature but that underlying professed epistemic beliefs can still inform individuals about how to evaluate contradictory information (see Hofer, 2001, 2016; Song et al., 2007). Hence, professed uncertainty beliefs can be regarded as a relatively stable underlying mindset regarding the tentativeness of knowledge, whereas enacted uncertainty beliefs are related to the activation of this mindset in a given context. Within this context, features such as the nature of the task, individuals' motivation, or prior knowledge might determine the extent to which they activate their more general, professed uncertainty beliefs (Hofer, 2016; Kienhues et al., 2016; Richter & Schmid, 2010). Similar to the interrelation of general and situational cognitive engagement (see 5.1.2), it appears that both general, trait-like aspects (professed uncertainty beliefs) and situational, state-like aspects (enacted uncertainty beliefs) are informative for understanding how individuals evaluate conflicting scientific information.

In summary, the present dissertation advances the understanding of how university students evaluate scientific controversies by investigating the role of uncertainty beliefs (professed and enacted), cognitive engagement (general and situational), and their interrelation. Figure 5.1 visually represents the general results of the three studies. It differentiates between the trait-like aspects of the constructs, which are located in the person, and the state-like aspects, which were assessed during task processing and are located in the context. Results showed that professed uncertainty beliefs had a direct association with the evaluation of scientific controversies as well as an indirect association as mediated by enacted uncertainty beliefs (Study 3) and situational cognitive engagement (Study 1). General cognitive engagement was also shown to be related to evaluation, but no correlations between general and situational cognitive engagement were found (Study 2). The dashed line between situational cognitive engagement and evaluation signifies that situational cognitive engagement as measured by pupil dilation was correlated with the controversy-evaluation test score in Study 1 but not in Study 2. Figure 5.1 also points toward possible directions for future research. For example, changing the context by using different tasks might produce a different pattern of results. Furthermore, the present dissertation did not investigate correlations between the different trait-like and state-like aspects of the measured constructs, represented by the faded, dashed lines.

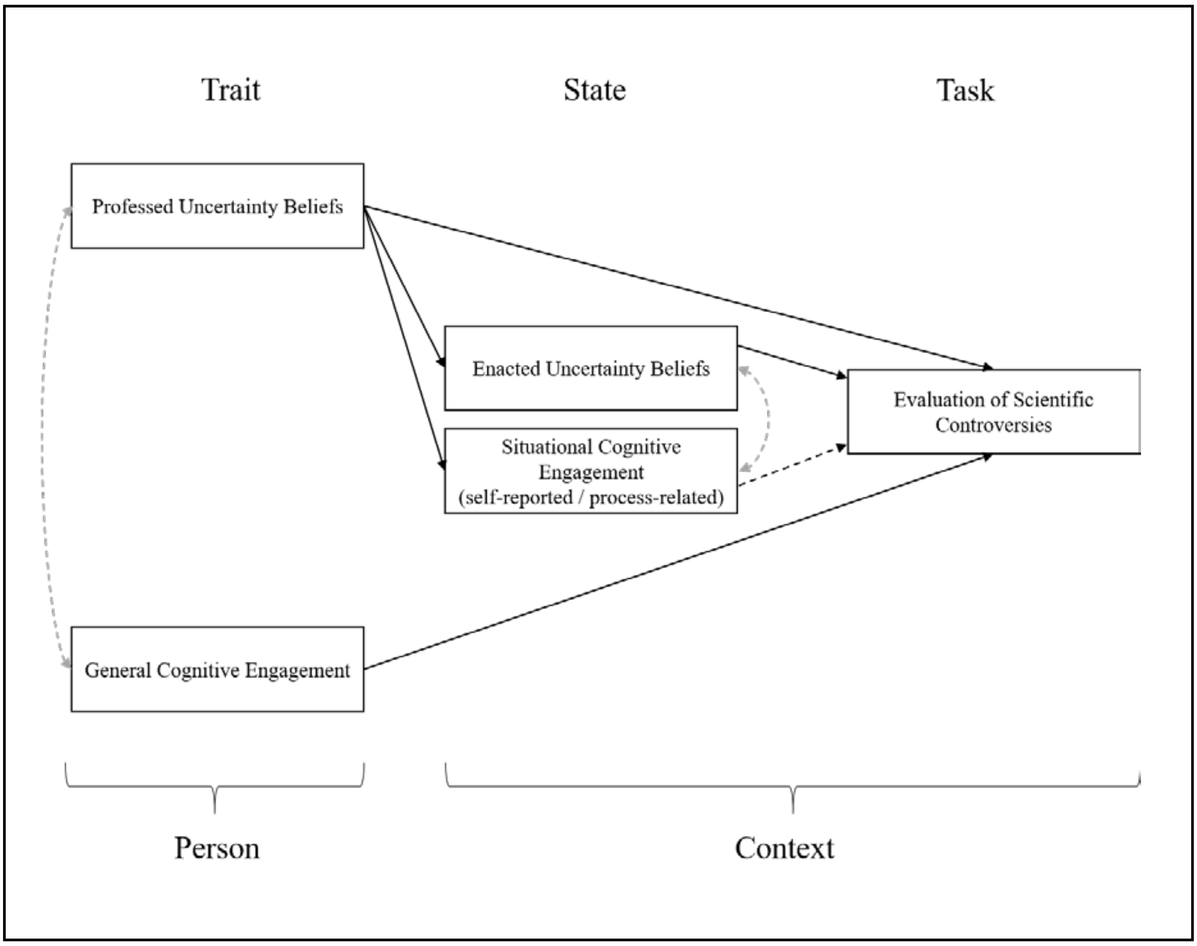

Figure 5.1 *Illustration of the general results of the present dissertation*

5.2 Strengths and Limitations

Before attending to the implications of the present dissertation, the following section will expand on its strengths and limitations. Three areas will be considered: the methodological approach, the individual measures that were used, and aspects of the sample. Although these areas comprise major strengths of the present dissertation, there are also downsides to the decisions made that should not be overlooked.

5.2.1 Methodological approach

All three studies in the present dissertation were conducted in a lab setting, with a high degree of standardization to ensure the comparability of the results across the studies. Several precautions were taken to increase the internal validity of the results. For example, physical factors that could influence the assessed eye-tracking data such as lighting and face-to-screen distance were held constant in all the studies. Further, in all studies, the trait-like variables (i.e., professed uncertainty beliefs in Studies 1 and 3 and general cognitive engagement in Study 2) were assessed in a preceding online questionnaire approximately 1 week before the lab sessions. This way, it was ensured that participants were not primed to answer in a certain direction regarding the state-like variables (i.e., enacted uncertainty beliefs in Study 3 and situational cognitive engagement in Studies 1 and 2). For example, in Study 3, completing the questionnaire on professed uncertainty beliefs directly before the controversy-evaluation test might have affected the way participants approached the task and hence altered their enacted uncertainty beliefs. On the downside, the lab setting limited the external validity of the results. The interplay of uncertainty beliefs, cognitive engagement, and the evaluation of scientific controversies might take on a different shape when individuals deal with scientific controversies in their home environment or when they work collectively on scientific controversies in a classroom context.

Regarding study design, the present dissertation comprises correlational studies with one measurement point for each variable. Some of the research questions were exploratory in nature because the present dissertation addressed gaps in prior research and integrated previously separate research traditions. Under these conditions, the correlational approach seems well justified. In order to further expand on the presented findings, however, other study designs are needed. For example, using experimental designs would allow for an investigation of individual and contextual factors that might contribute to individuals' uncertainty beliefs and cognitive engagement when evaluating scientific controversies, such as different levels of expertise or different task instructions (see Brand-Gruwel, Kammerer, van Meeuwen, & van Gog, 2017; Gil et al., 2010; Kirschner et al., 2011). Furthermore, longitudinal designs using multiple measurement points could account for the development, or, in the case of intervention studies, for the malleability of uncertainty beliefs, cognitive engagement, and their interrelation (see also Bråten, 2016; Hughes, Luo, Kwok, & Loyd, 2008; Patall et al., 2016).

Further, the present dissertation exemplifies the usefulness of integrating different data sources. In all three studies, offline measures (e.g., questionnaires) and online measures (e.g., eye-tracking data) were combined, with the added value that the triangulation of different data sources provided more insights than when inspected individually. For example, the interpretability of eye-tracking measures can be increased by using additional data sources (e.g., Gerjets, Kammerer, & Werner, 2011; Jarodzka, Holmqvist, & Gruber, 2017; Mason & Florit, 2018). In this regard, the present dissertation points out some important issues regarding the interrelation of online and offline measures. It has to be kept in mind that the theoretical assumption behind questionnaire data (i.e., offline measures) is that individuals are principally aware of the construct of interest and that they are able to express their level of agreement with questionnaire items. Online data such as eye tracking, on the other hand, are usually nonintrusive and observational, thereby getting closer to individuals' cognitive processes of which they are not necessarily aware (Mason & Florit, 2018; Rayner, 1998). The present dissertation has demonstrated that both offline and online measures have their merits, given that the measurement approach is in line with theoretical assumptions. Take Study 2, for example. It is plausible to assume that individuals can make judgments of their general cognitive engagement regarding science but also that they are unaware of the extent to which they invest in situational cognitive engagement when dealing with a specific science-related task. Hence, rather than determining which approach is more valid, a combination of different measures has been shown to be beneficial for answering the pressing research questions presented in this dissertation.

Nonetheless, some of the measures used in the three studies were based on similar modalities, whereas others were based on different modalities, which might have biased the results. For example, in some measures such as those targeting professed uncertainty beliefs, general cognitive engagement, and evaluation performance, participants agreed or disagreed with predefined test or questionnaire items. On the other hand, enacted uncertainty beliefs were assessed with cued retrospective reports, and situational cognitive engagement was measured with pupil dilation. Developing measures that are able to draw on similar data sources in future studies might help to reduce measurement variance. Unfortunately, measures such as questionnaires about enacted uncertainty beliefs or implicit cognitive engagement do not seem feasible. Moreover, when integrating different measures, researchers should not strive for a variety of measures and methods as an end in itself. Rather, it is necessary to align the research question, construct definition, and chosen indicators (Bromme et al., 2010; Miller, 2015; Sandoval et al., 2016). By deliberately combining different indicators in the present dissertation, it was possible to show how uncertainty beliefs and cognitive engagement, both individually and jointly, influence how individuals evaluate scientific controversies. In the following, the merits and risks of individual measures that were integrated in the present dissertation are discussed in more detail.

5.2.2 Measures

All three studies in the present dissertation used the same controversy-evaluation test (Kramer et al., 2019; Oschatz et al., 2017) as the central dependent variable. This test required the evaluation of scientific controversies across five different topics. From a general perspective, the focus on scientific controversies addresses an important topic because contradictory scientific information is a highly relevant issue that is related not only to individuals' general understanding of science but also to their academic careers and personal life decisions (Bromme & Goldman, 2014; Hess, 2008; Sinatra et al., 2014; Sinatra & Hofer, 2016). From a research perspective, by using a variety of scientific issues on the controversy-evaluation test, one shortcoming of prior research on evaluations of contradictory information was overcome, and this was the restriction to only one controversial topic (see also Bråten et al., 2011). Furthermore, whereas prior research often used arbitrary study materials from which participants' evaluation performance needed to be inferred retrospectively, using a standardized test made it possible to obtain test scores directly from the study materials. However, this high level of standardization also has its limitations. The study settings required participants to read the controversial texts passively in a solo setting, with prescribed scientific positions. At least two alternative ways of investigating the evaluation of scientific controversies are conceivable, and both have implications for how uncertainty beliefs and cognitive engagement might influence evaluation. First, participants could be allowed to freely work with the controversial texts, for example, by making annotations or by discussing their ideas with peers (Valanides & Angeli, 2011). The resulting products could then be analyzed as additional data sources. For example, references to participants' enacted uncertainty beliefs could be found in their peer discussions, and the number and quality of their annotations in the texts could be used as indicators of cognitive engagement. On a side note, in their ICAP framework, Chi and Wylie (2014) differentiated between interactive, constructive, active, and passive facets of cognitive engagement. Participants engaging in the abovementioned peer discussions would be assumed to relate to the most elaborate, interactive facet of cognitive engagement. However, many of the assumptions in the ICAP framework are in stark contrast to the definition of cognitive engagement in the present dissertation because they have a strong focus on behavioral rather than on cognitive aspects, and they show overlaps with other constructs such as self-regulation. A second alternative approach to investigating individuals' evaluations of scientific controversies would be to let them search and select different information sources pertaining to a controversial issue (either freely or using preselected material), rather than confronting them with predefined positions (Gerjets et al., 2011; Salmerón et al., 2013). Less performance-oriented task conditions such as a Web search might also trigger different aspects of uncertainty beliefs (Mason, Boldrin, & Ariasi, 2010b) or cognitive engagement (Blumenfeld et al., 2006). However, introducing such degrees of freedom would have hampered the degree of standardization of the studies in the present dissertation and with it the comparability of results. Hence, in this trade-off between standardization and comparability on the one hand and authenticity on the other hand, the present dissertation chose to focus on the former, following a more rigorous approach to answer the research questions.

Another strength relating to the employed measures is that, regarding their domain-specific nature (see 1.3.1), professed uncertainty beliefs (Studies 1 and 3) and general cognitive engagement (Study 2) were assessed in relation to the domain of science. Thus, the present dissertation followed calls for more domain-specific assessments of epistemic beliefs (Mason, 2016) and engagement (Sinatra et al., 2015). However, this domain-specific approach does not allow for conclusions regarding other domains or individuals' uncertainty beliefs and cognitive engagement on a more general level (Buehl & Alexander, 2001; Fredricks et al., 2004; Green et al., 2007; Muis et al., 2006)

Moving on to another important measure used in the present dissertation, by using eye-tracking technology, it was possible to use a pupil as a measure of cognitive engagement during test processing in Studies 1 and 2. This approach builds on ample evidence showing that pupil dilation is indicative of increased cognitive engagement (or, in the terminology used in cognitive load theory: mental effort) during problem solving (Beatty, 1982; Korbach et al., 2017; Krejtz, Duchowski, Niedzielska, Biele, & Krejtz, 2018; Scharinger, Kammerer, & Gerjets, 2015; Wang, 2011). With this relatively objective measure, participants' online cognitive engagement could be measured without being biased by social desirability. However, other factors might have biased participants' pupil dilation, making it less straightforward to interpret this measure as situational cognitive engagement. For example, emotional arousal has also been shown to influence pupil diameter (Bradley, Miccoli, Escrig, & Lang, 2008). It is worth mentioning that pupil dilation was a strong predictor of performance in the controversy-evaluation test in Study 1 but not in Study 2. The differences between these two studies were that they took place in different labs (though with comparable conditions) and drew on samples with different compositions. Whereas participants in Study 1 had a variety of study backgrounds, Study 2 investigated only science students. It is possible that the science students in Study 2 already had high levels of expertise in reading contradictory scientific information, and their familiarity with this type of task might have obviated their need to invest in cognitive engagement in order to complete the task. This assumption is in line with the predictions of the Expertise Reversal Effect (Kalyuga, Ayres, Chandler, & Sweller, 2003), which states that the effectiveness of instructional designs can be higher for inexperienced learners than for experienced learners. However, it has also been shown that the integration of different information sources can impose extraneous cognitive load (van Merriënboer & Sweller, 2005), and it can be assumed that experienced learners should be able to compensate for this constraint on cognitive resources, actually enabling them to invest more mental effort than inexperienced learners when working on the controversy-evaluation test. Clearly, more research regarding pupil dilation in the light of different individual and contextual variables is needed to substantiate this measure as an indicator of effortful cognitive processing. Unfortunately, the algorithms used by eye-tracking systems to calculate pupil size remain a “black box,” preventing researchers from scrutinizing the possible implications of this measure.

Finally, in the present dissertation, well-established measures were used to assess professed and enacted uncertainty beliefs. Following the assumption that individuals possess a relatively stable and explicit epistemic belief system, questionnaires are the means of choice for assessing professed uncertainty beliefs. However, the possibility that individuals have at least to some degree not yet formed stable uncertainty beliefs cannot be entirely excluded. In this case, their responses to questionnaire items targeting their professed uncertainty beliefs might reflect individuals’ ad hoc constructions rather than their preexisting beliefs (Pieschl et al., 2014; Sinatra, 2016). One way to address this question would be to use cognitive interviews while participants fill out the questionnaire (Muis et al., 2014). Unlike professed uncertainty beliefs, enacted uncertainty cannot be directly assessed but must be inferred (Briell, Elen, Verschaffel, & Clarebout, 2011). In Study 3, this was achieved by using cued retrospective reports (van Gog et al., 2005). This procedure has been shown to be effective in producing rich and meaningful verbal data while at the same time avoiding the risk of interview procedures to point participants’ answers in a desired direction (Fox, Ericsson, & Best, 2011; Hyrskykari, Ovaska, Majaranta, Räihä, & Lehtinen, 2008). On the downside, cued retrospective reports require a certain level of inference when the verbal data are transcribed, segmented, and coded. This is particularly the case for the controversy-evaluation test that was used to collect participants' cued retrospective reports. Rather than directly prompting participants to elaborate on their ideas regarding the uncertainty of knowledge, their verbal statements about how they responded to claims regarding the different scientific controversies were assessed, which is a much less immediate approach for capturing enacted uncertainty beliefs. Lest inference would turn into arbitrariness when coding the verbal protocols, care was taken to develop a consistent coding scheme that was used to extensively train the raters involved in the coding process. Using cued retrospective reports in combination with a standardized test also points to other possible applications of this measure in terms of test development to gain insights into what individuals are thinking while completing a task or answering test items (Leighton, 2004).

In summary, the present dissertation used appropriate and innovative measures to answer the different research questions. However, in some cases, these measures were stretched to their limits, and more basic research is needed to determine the psychometric properties of these measures (Fredricks & McColskey, 2012; Mason, 2016). Most importantly, the refinement of theories and methods should work hand in hand in order to develop more precise and valid indicators of uncertainty beliefs and cognitive engagement.

5.2.3 Sample

In all three studies in the present dissertation, university students were investigated. As argued earlier, from a normative perspective, this target group appears ideally suited to investigate the presented research questions. The outcome measure (i.e., evaluating scientific controversies) is highly relevant for their academic and personal lives. The same can be said for both of the independent variables used in the present dissertation. The uncertainty of scientific knowledge is considered a central educational goal in university science education (Jehng, Johnson, & Anderson, 1993; Kirch, 2012). Another goal is the promotion of cognitive engagement, especially given the decline in cognitive engagement as students' academic careers progress (Osborne et al., 2003; Patall et al., 2016). From an empirical perspective, prior research has suggested that it is not until young adulthood that individuals can develop distinct beliefs about the uncertainty of knowledge (Kuhn et al., 2000; Wildenger et al., 2010). Therefore, the samples used in the present dissertation seem appropriate.

There are, however, two downsides regarding the size and the specificity of the samples. First, the sample sizes in all three studies were relatively small, which is a common problem related to the assessment of online measures. As Greene, Yu, and Copeland (2014) noted in the context of a study using think-aloud protocols, “the data collection effort is extremely labor intensive, posing a formidable constraint to researchers hoping to share meaningful findings backed by strong statistical support” (p. 58). The authors reported that it required approximately 1 workday per study participant to prepare the verbal data for analysis. The present dissertation, which used both eye-tracking technology and cued retrospective reports, is no exception. In this regard, the methods that were used were able to provide rich data, but they also came along with small sample sizes. Obtaining larger samples would be particularly useful to further investigate the research questions of the present dissertation. In Studies 2 and 3, state-like and trait-like aspects of uncertainty beliefs and cognitive engagement were compared. Large samples would allow for the modeling of latent variables and for the integration of multiple measures into a latent-state-trait approach in which the trait-like and state-like aspects of the measured constructs could be examined with more detail and precision. A promising way to achieve larger samples can be found in recent developments in the automatized assessment of controversy evaluation in general (Magliano, Hastings, Kopp, Blaum, & Hughes, 2018) or automatized assessments of epistemic beliefs (Appel, Lang, Kammerer, Gerjets, & Kasneci, 2019) and engagement (D’Mello, Dieterle, & Duckworth, 2017) in particular. If these approaches can be shown to provide reliable and valid data, they could sidestep the limitations of more time-consuming methodological approaches.

A second limitation of the sample refers to its specificity in terms of age group, educational level, and culture. Results should therefore not be overgeneralized to populations other than young adults in a Western university context. Regarding age, limited working memory capacity in older adults has been shown to affect the strategies they adopt when evaluating controversial information (Stine-Morrow & Radvansky, 2018) as well as their cognitive engagement (Ennis, Hess, & Smith, 2013). Even though age was not a significant predictor in either of the studies in the present dissertation, the variance of this variable was too limited to provide meaningful results. Regarding educational level, a study by Kammerer, Amann, and Gerjets (2015) is one of the few examples where adults without a university education were investigated. Study participants evaluated multiple websites with respect to medical issues, with epistemic beliefs predicting their Web search behavior. More research comparing samples with different educational background is needed to allow for more generalizable conclusions regarding the role of uncertainty beliefs and cognitive engagement (Fredricks et al., 2016; List, Peterson, Alexander, & Loyens, 2018). Regarding cultural aspects, like most research in the field, the present dissertation used samples of participants from a Western culture. In fact, German as participants' first language was a condition for participation in all three studies, given the text-based nature of the evaluation task. However, other cultural backgrounds might differ in terms of the observed variables (Hofer & Sinatra, 2010). For example, the Confucian heritage in many Eastern cultures places a smaller need to integrate contradictory knowledge claims, and it ascribes more value to cognitive engagement during learning (Buehl, 2008; Chan, 2008).

5.3 General Implications and Future Directions

With epistemic beliefs and engagement, the present dissertation focused on two multifaceted and complex constructs that are characterized by inconsistent theoretical and methodological approaches in the literature (Boekaerts, 2016; Briell et al., 2011; Reschly & Christenson, 2012). By using the evaluation of scientific controversies as a study context, the present dissertation focused on specific dimensions of these constructs (i.e., uncertainty beliefs and cognitive engagement) because these dimensions have many theoretical and empirical links to the evaluation of contradictory information (e.g., Bråten, Brante et al., 2018; King & Kitchener, 2002; Stadtler & Bromme, 2014). By offering in-depth analyses using innovative measurement approaches, the present dissertation contributes to the refinement of construct definitions regarding uncertainty beliefs, cognitive engagement, and the intersection of these research traditions. The implications discussed below will address aspects of both of these variables as well as more general aspects relating to the evaluation of scientific controversies. First, the general theoretical implications of the presented results will be discussed, before deriving possible directions for future research (see 5.3.1). Then, implications for practice will be discussed, regarding both educational contexts and generally (see 5.3.2).

5.3.1 Implications for research

On a general level, two aspects of the presented findings deserve consideration. First, the question of which level (or levels) uncertainty beliefs and cognitive engagement are conceptualized on in the present dissertation is related to trait-like and state-like aspects of these constructs. Second, the question of the nature of the investigated relations is related to whether strong uncertainty beliefs and high cognitive engagement are always beneficial. The discussion will then attend to unanswered questions and possible directions for future research.

Differentiating between trait-like and state-like aspects

A recurring theme in the present dissertation is the trait- and state-like nature of the investigated constructs. This addresses important research questions, for example, regarding the level on which the respective constructs operate and how they impact students’ reasoning processes (Mason & Bromme, 2010). Regarding uncertainty beliefs, the integration of professed and enacted beliefs (see Study 3) is in line with several calls for the clarification of how different conceptualizations are interrelated rather than continuing with the fragmentation of different approaches. For example, Hofer and Sinatra (2010) concluded that the epistemic belief construct may take on different forms that need to be approached using a more inclusive view than is currently the case. Similarly, Greeno (2015) argued that general and situational aspects of cognition should be integrated in order to better understand how these aspects interact in different contexts. Regarding general levels, the present dissertation refers to professed uncertainty beliefs as trait-like aspects of these beliefs and not personality traits in the classical sense. That is, while acknowledging the dispositional nature of individuals' professed and general beliefs, the malleable nature of individuals' enacted and contextualized beliefs is also kept in mind (Hofer & Sinatra, 2010; Kienhues et al., 2016). Regarding the state-like nature of uncertainty beliefs, several intervention studies have demonstrated that uncertainty beliefs are indeed mutable (see Bråten, 2016, for an overview). Hence, by accounting for trait-like and state-like aspects, the present dissertation addresses the important question of how professed and enacted epistemic beliefs interact and how both impact learning and reasoning in science (Alexander, 2016; Schraw & Olafson, 2003). In doing so, the present dissertation builds a bridge between dimensional models, which state that epistemic beliefs can be directly assessed and developed, and situative models, which claim that epistemic beliefs can only be revealed through practice (see also Mason, 2016). Results indicate that professed uncertainty beliefs might serve as a general schema or frame that influences individuals' tendency to embrace conflicting information, whereas enacted uncertainty beliefs are related to the context-specific activation of these frames (Fives & Buehl, 2017; Song et al., 2007). Arguably, contexts other than the evaluation of scientific controversies as implemented in the present dissertation might be more or less effective for the enactment of individuals' uncertainty beliefs (Kienhues et al., 2016). For example, if the different scientific positions were presented as more intertwined and less clearly separated than in the controversy-evaluation test used in the present studies, individuals might not realize that they are dealing with a task for which their professed uncertainty can be adaptive because they often do not readily detect contradictions between scientific positions (Stadtler, Scharrer, Brummernhenrich, & Bromme, 2013). Do the presented results justify the conclusion that professed and enacted uncertainty beliefs can generally be integrated under a single framework, or does this only apply to the specific context used in the present dissertation? To answer this question, more theorizing and empirical studies such as presented in this dissertation are needed to show whether a term like epistemic cognition might serve as an overarching construct for professed and enacted epistemic beliefs or whether individuals' conceptions of knowledge and knowing are too diverse of a phenomenon to integrate them under a single framework (Alexander, 2016; Hofer, 2016; Kienhues et al., 2016).

Like uncertainty beliefs, cognitive engagement was conceptualized in the present dissertation as consisting of trait-like aspects (general cognitive engagement) and state-like aspects (situational cognitive engagement). This is in line with the theoretical assumption that individuals' actual engagement during a task might be the result of individual (i.e., stable) and situation-specific (i.e., contextual) factors (Fredricks et al., 2004; List & Alexander, 2017; Wang & Degol, 2014). However, results from Study 2 were less consistent than for uncertainty beliefs because no correlations were found between indicators of general and situational cognitive engagement. However, the results do indicate that measures that have been used interchangeably in prior research may in fact refer to distinct facets of cognitive engagement. Moreover, general and situational measures of cognitive engagement were differentially correlated with other relevant variables. These findings stress that it is important for research to clearly specify which aspects of cognitive engagement (general or situational) are under investigation and which variables are predicted by these different aspects. Presumably, general cognitive engagement will have stronger connections to broader concepts such as students' motivation or interest with respect to a particular knowledge domain, whereas situational cognitive engagement might be more closely associated with learning strategies that are enacted during a particular task. The finding in Study 2 that there were no associations between trait-like aspects and state-like aspects of cognitive engagement does not necessarily mean that the two are fundamentally different. By using different task types, instructional settings, or knowledge domains in the study of general and situational cognitive engagement, a meaningful relation between these facets may yet be found (Guthrie et al., 2012; Kirschner et al., 2011; Pintrich & Schrauben, 1992; Wiley et al., 2018). On this note, the present dissertation points to a problematic aspect of engagement research in general, which is "characterized presently by specialization, fragmentation, and proliferation rather than by synthesis" (Boekaerts, 2016, p. 82). What is needed is a refinement of the construct definitions of cognitive engagement (and other engagement dimensions). The proposed definition of cognitive engagement (see 1.2.2) might serve as a starting point from which to investigate a couple of pressing research questions, such as the facets that cognitive engagement is composed of, how they interact, how we can best measure them, and how they impact cognitive processes.

In summary, the advantage of integrating trait-like and state-like aspects in the present dissertation is that it allows for a more detailed and flexible investigation of the measured constructs. Focusing exclusively on stable and general (i.e., trait-like) aspects would imply that uncertainty beliefs and cognitive engagement are immutable constructs, dispensing with attempts to foster them through interventions. On the other hand, conceptualizing uncertainty beliefs and cognitive engagement as fluid and entirely dependent on context (i.e., state-like) would obliterate the attempt to draw any generalizable conclusions. This differentiation is also connected to the issue of domain-generality versus domain-specificity (see 1.3.1). It is fair to assume that trait-like aspects (i.e., professed uncertainty beliefs and general cognitive engagement) are more relevant to the domain of science in general, whereas state-like aspects (i.e., enacted uncertainty beliefs and situational cognitive engagement) have an effect on more specific factors such as evaluation processes during a particular scientific controversy (see, e.g., Study 2). The challenge for research is to define appropriate levels of granularity that are general enough to make a contribution to the bigger puzzle and also specific enough to account for the contextualized nature of the constructs (Azevedo, 2015; Hofer, 2005). The present dissertation addresses this issue by providing evidence for the complex and multilayered nature of uncertainty beliefs and cognitive engagement (Buehl & Alexander, 2001; Fredricks et al., 2004; Hofer & Pintrich, 1997).

Linear relations

A second issue worth mentioning refers to the nature of the assumed relations between uncertainty beliefs, cognitive engagement, and the evaluation of scientific controversies. The hypotheses in the present dissertation generally stated that high values on the independent variables (i.e., strong uncertainty beliefs and high cognitive engagement) lead to better performance on the controversy-evaluation test. This came along with statistical procedures that are based on the assumption of linear relations between these variables. However, the question that arises is whether the normative assumption of “the more, the better,” which is implicit to these hypotheses, is appropriate. As for uncertainty beliefs, past research has indeed referred to beliefs in uncertain knowledge as “sophisticated,” whereas beliefs in certain knowledge have been considered “naïve.” Recently, the attribution of such normative values has been questioned, given findings that epistemic beliefs that were considered sophisticated have led to poorer learning outcomes (Bråten, Strømsø, & Samuelstuen, 2008; Lee, Liang, & Tsai, 2016; see also Bråten et al., 2016; Hofer, 2016; Sinatra et al., 2014). In line with this reasoning, the present dissertation did not refer to beliefs in uncertain knowledge as sophisticated but rather stated that uncertainty beliefs can be more or less advanced and adaptive in relation to a particular context. As argued earlier (see 1.1.4), because scientific controversies are tentative by nature (Britt & Rouet, 2012), they provide an ideal context for the study of uncertainty beliefs, which are considered an adaptive mindset for dealing with scientific controversies (e.g., Bråten et al., 2011; Schraw et al., 1995; Strømsø et al., 2008). Still, it can be disadvantageous for individuals to regard all knowledge as uncertain. For example, questioning the certainty of fundamental observations such as “the earth is round” will hardly lead to productive scientific reasoning (Hammer & Elby, 2002; Kienhues et al., 2016; Sinatra et al., 2014). Arguably, the more complex the knowledge pertaining to a scientific issue is, and the more it requires inferences rather than mere descriptions, the more adaptive uncertainty beliefs will be to cope with this knowledge (Greene & Yu, 2014). This is also in line with constructivist approaches to knowledge generation, stating that knowledge is not an objective entity in a platonic sense but is actively constructed within human communities and is therefore inherently subjective (Baxter Magolda, 2004; Buehl & Alexander, 2001; Dole & Sinatra, 1998).

The question of the circumstances under which uncertainty beliefs are adaptive also points to an important difference between the belief system approach and the developmental approach (see 1.1.1). Whereas in the belief system approach, uncertainty beliefs are usually located on one dimension ranging from certain (i.e., absolute and fixed) knowledge to uncertain (i.e., tentative and evolving) knowledge (Hofer & Pintrich, 1997; Schommer, 1990), the developmental approach differentiates between the three stages of absolutism, multiplism, and evaluativism (Kuhn, 1991). Theoretically, beliefs in certain knowledge as conceptualized in the belief system approach correspond with the absolutist stage, and beliefs in uncertain knowledge are in line with the multiplist stage. However, there is no such correspondence for the evaluativist stage, and it is unclear to date how the certainty-uncertainty continuum is related to evaluativism (Hofer & Sinatra, 2010). Whereas the midpoint of the uncertainty dimension in the belief system approach implies believing that knowledge in general is moderately certain, an evaluativist would differentially evaluate the certainty of knowledge on the basis of evaluation criteria such as the consistency between claims and evidence (Kuhn, 2001). Therefore, readers are cautioned not to consider uncertainty beliefs as portrayed in the present dissertation as a form of naïve multiplism (Peter, Rosman, Mayer, Leichner, & Krampen, 2016; Sandoval, 2005) in the sense that individuals are unable to reach any conclusions because all knowledge is seen as tentative. To be sure, the models presented in this research are, like any scientific model, an approximation of uncertainty beliefs, but this is not meant to account for every possible implication and context. Uncertainty beliefs in practice are likely more complex, and students can hold mixed beliefs, including both uncertain and certain aspects of scientific knowledge (Songer & Linn, 1991). Whereas in many cases, a more fluid and flexible perspective to uncertainty beliefs would be more appropriate (Mason & Bromme, 2010), uncertainty beliefs should generally be regarded as a helpful tool that gives individuals pause to assess the veracity of different knowledge claims instead of leaping to hasty conclusions. For example, uncertainty beliefs might elicit epistemic doubt in the sense of Bendixen and Rule's (2004) integrative personal epistemology model (see 1.3.2), facilitating a careful examination of inconsistent information. More often than not, knowledge is in fact more ambiguous than is communicated to laypeople (Bromme & Goldman, 2014). Following a “when in doubt, doubt” heuristic might therefore be useful for the critical evaluation of information, a view that is in line with conceptualizations of epistemic beliefs as lenses and filters (Bromme et al., 2010; Fives & Buehl, 2017). In short, although there might be no such thing as “sophisticated” uncertainty beliefs, individuals can still evince sophisticated epistemic thinking in the sense that they know where and how to make use of their beliefs (see also Barzilai & Zohar, 2012). However, complex mental tasks such as the evaluation of scientific controversies can only be accomplished through the aid of additional strategies such as the investment of cognitive engagement.

Cognitive engagement, as conceptualized in the present dissertation, was also assumed to have linear relations with evaluation performance. The arguments presented above regarding uncertainty beliefs also apply to cognitive engagement. In most cases, it seems like a reasonable strategy to invest large amounts of cognitive engagement in order to solve a complex task. However, there are limits to this assumption. It has been suggested that successful learners can adjust their level of cognitive engagement in accordance with task demands, rather than demonstrating equal levels of engagement during all phases of a task (Greene, Dillon, & Crynes, 2003). Other studies have shown that merely being cognitively engaged in science-related activities does not always entail a more advanced understanding of science (Kuhn et al., 2017; McConney et al., 2014). Theoretical approaches that differentiate between shallow and meaningful cognitive engagement (e.g., Ravindran et al., 2005; Walker et al., 2006) might be able to explain these discrepancies. These models assume qualitatively distinct cognitive strategies, with advanced strategies signifying meaningful cognitive engagement and leading to favorable learning outcomes in comparison with simple strategies and shallow cognitive engagement. However, the present dissertation makes the point that it is not reasonable to distinguish between qualitatively different aspects of cognitive engagement (see 1.2.2) because advanced strategies that make cognitive engagement meaningful are best described by existing concepts such as self-regulated learning and should therefore not be confused with the cognitive engagement construct. A more plausible explanation for why sometimes high cognitive engagement does not result in desired outcomes is offered by cognitive load theory. Individuals have only limited cognitive resources at their command, which constrains the amount of mental effort (defined as situational cognitive engagement in the present dissertation) they are able to invest in a task (Kirschner et al., 2011; Paas et al., 2003). When load is imposed on individuals’ cognitive resources by unintended factors such as tasks that are too difficult to understand, they might not be able to exploit their cognitive potential by mobilizing the amount of effort that is needed for successful learning. Therefore, careful instructional design is needed to provide learning opportunities that facilitate, rather than discourage, cognitive engagement (see 5.3.2).

In conclusion, high manifestations of uncertainty beliefs and cognitive engagement are theoretically desirable, but sometimes practical constraints can limit the adaptiveness of these constructs. Moreover, neither of the two variables is likely to be effective in isolation but needs to be accompanied by other constructs. In line with Study 1, for example, participants' professed uncertainty beliefs might have served as a guiding system that advised them on the investment of cognitive engagement in order to make sense of the contradictory positions presented in the controversy-evaluation test. However, yet other variables might facilitate the effects of uncertainty beliefs and cognitive engagement in the light of scientific controversies. These, next to other open questions for future research, are discussed below.

Future directions

With uncertainty beliefs and cognitive engagement, the present dissertation examined two constructs that play key roles in both educational and cognitive science. By focusing on the evaluation of scientific controversies, many pressing issues regarding the nature and functionality of these constructs could be addressed. However, there are still some open questions that could not be investigated with the present research design and study context. Therefore, the presented results also point to unanswered questions and hence to promising directions for future research. These open questions are related to (a) the causal mechanisms of the observed variables, (b) relations with other dimensions of epistemic beliefs and engagement, (c) implications for domains other than science, and (d) other explanatory variables that could help explain the results on both a task level and an individual level.

First, given the correlational data structure, it was not possible to make strong causal claims about the observed relations. For example, whereas it was assumed that professed uncertainty beliefs would manifest in enacted uncertainty beliefs (Study 3), the opposite effects might exist as well. It can be assumed that the repeated enactment of uncertainty beliefs in different contexts might eventually shape individuals' professed uncertainty beliefs. That is, when individuals have the experience that enacting uncertainty beliefs when dealing with contradictory information is adaptive, they might habituate this successful strategy into a more general representation of professed uncertainty beliefs, which can then be applied to other tasks (see also Barzilai & Zohar, 2012). However, how enacted epistemic beliefs might influence professed epistemic beliefs is still an open question (Mason, 2016). The same bidirectional relation might be assumed for cognitive engagement. However, because Study 2 did not find significant correlations between general and situational cognitive engagement, this conclusion remains more speculative.

Second, whereas the present dissertation made a strong point about why in-depth analyses of particular dimensions of engagement (Study 2) and epistemic beliefs (Study 3) can be worthwhile, the results provide no information about the relations with other dimensions in the respective frameworks (see Fredricks et al., 2004; Hofer & Pintrich, 1997). Therefore, one possible direction for future research is to investigate whether the results of the present dissertation can be replicated for other dimensions, that is, whether the assumed dual nature of trait-like and state-like aspects is a general feature of the overarching constructs or only applies to uncertainty beliefs and cognitive engagement. For example, are there also professed and enacted facets of other epistemic belief dimensions such as justification for knowing? Is it possible to differentiate between general and situational facets of behavioral engagement? Another potential direction for future research lies in an integrated investigation of different epistemic belief and engagement dimensions that were specified in their overarching frameworks. More studies are needed to investigate the interplay of different dimensions of epistemic beliefs (e.g., Kampa, Neumann, Heitmann, & Kremer, 2016) and engagement (e.g., Ben-Eliyahu et al., 2018; Fredricks, Hofkens, Wang, Mortenson, & Scott, 2018) in science. For example, how can the justification dimension of epistemic beliefs explain individuals' evaluation of scientific controversies above and beyond the uncertainty dimension? The justification dimension, which entails whether or not individuals believe that science can provide justified knowledge claims, might serve as a prerequisite for whether individuals bother to evaluate scientific controversies or rely on their intuition instead. Regarding engagement, does high cognitive engagement when reading scientific controversies also mean that individuals will be behaviorally engaged, for example, during scientific debates in the classroom (cf. Renninger & Bachrach, 2015)? Furthermore, even in seemingly "cold" and rational tasks such as the evaluation of scientific controversies, affective aspects should not be overlooked. This is true for the dimension of emotional engagement but also for emotional aspects of epistemic beliefs (e.g., Trevors, Muis, Pekrun, Sinatra, & Muijselaar, 2017). For instance, individuals who experience cognitive ease during information processing can have feelings of confidence, satisfaction, or even flow, whereas not being able to process contradictory information can result in unpleasant feelings of difficulty (Csikszentmihalyi, 1997; Efklides, 2006; see also Barzilai & Zohar, 2016). In this sense, future research should not blindly follow the assumption that individuals readily evaluate contradictory scientific information but should continue to investigate how individuals' epistemic evaluations of and engagement with science can be ensured (Bromme & Jucks, 2018; Garrett & Weeks, 2017; Ståhl & van Prooijen, 2018). In order to do so, future research that is aimed at the integration of different dimensions can draw on theoretical models that specify the role of different epistemic belief dimensions (Bråten et al., 2011; see 1.1.3) and different engagement dimensions (List & Alexander, 2017; see 1.2.3) in the evaluation of scientific controversies.

Third, future research should expand the presented findings to knowledge domains other than science. The focus on the domain of science in the present dissertation was motivated by the fact that both uncertainty beliefs and cognitive engagement are related to successful learning and achievement in science (e.g., Ben-Eliyahu et al., 2018; Elby et al., 2016; Mason et al., 2013; Schmidt et al., 2018), whereas at the same time, studies in the domain of science are underrepresented, particularly in engagement research (Azevedo, 2015; Sinatra et al., 2015). Still, in domains other than science, the way knowledge is structured and communicated can be very different (Neumann, Parry, & Becher, 2010; Olafson & Schraw, 2006; Sandoval, 2016). This point concerns the issue of the domain-specificity of uncertainty beliefs and cognitive engagement. Specifically, two questions about the relevance of the respective domain arise. First, how do students' uncertainty beliefs and cognitive engagement affect the ways in which they evaluate knowledge in different domains? Second, how do the conventions of students' own domain of study shape their uncertainty beliefs and cognitive engagement (Fredricks et al., 2018; Leach et al., 2000; Rosman, Mayer, Kerwer, & Krampen, 2017; Trautwein & Lüdtke, 2007)? Research suggests that students in "soft" sciences have stronger uncertainty beliefs than students in "hard" sciences (Jehng et al., 1993; Paulsen & Wells, 1998) but also that students generally tend to attribute high levels of certainty to knowledge in (natural) sciences (Hofer, 2000; Kuhn et al., 2000). Because the focus of the present dissertation did not lie in a comparison of different domains, the data could not provide answers to these questions about differences within or between students. Presumably, in domains where scientific controversies and ill-structured knowledge are more common, such as history or jurisprudence (Alongi et al., 2016; Kitchener, 1983), uncertainty beliefs will be more productive than in more well-structured domains such as mathematics (cf. Greene, Torney-Purta, Azevedo, & Robertson, 2010). Note, however, that the categorization of different subjects into "hard" and "soft" fields is not trivial and might best be described by a continuum rather than by a dichotomy (Biglan, 1973). Future research could address these issues by using between-subject designs, where individuals with different study backgrounds evaluate the same controversial issue. They can also use within-subject designs, where individuals evaluate controversies from different knowledge domains.

Fourth, other explanatory variables that have not been accounted for in the present dissertation should be investigated in future research in order to further explain the relation between the measured constructs from a broader perspective. These variables could be related to aspects of the task or to individual differences. Regarding aspects of the tasks, the controversy-evaluation test used in the three studies had a strong focus on the evaluation of competing claims. However, other tasks aspects might also contribute to how individuals evaluate the information they encounter in a scientific controversy. Among these factors are textual features such as comprehensibility (Scharrer et al., 2013; Scharrer, Stadtler, & Bromme, 2014), discourse style (Thomm & Bromme, 2012), plausibility of the presented claims (Münchow et al., 2019), presentation format (Salmerón, Gil, & Bråten, 2018; Stadtler et al., 2013), or the goals that are connected with the evaluation task such as summary or argumentation (Bråten & Strømsø, 2010; Gil et al., 2010), with complex interactions existing between these different aspects (Kendeou et al., 2011; Thomm & Bromme, 2016). Different task conditions have also been shown to influence eye-tracking data (Dillon, 1985), which has to be kept in mind when using eye tracking to assess evaluation processes. The findings reported here might be incorporated by future epistemic belief and engagement research in order to provide a deeper understanding of how the nature of evaluation tasks can either facilitate or impair learning.

Regarding individual differences, future research could explore several variables that have been shown to be related to uncertainty beliefs, cognitive engagement, or both. Given that the evaluation of scientific controversies is a complex task that requires the interaction of multiple variables in individuals, it is evident that neither uncertainty beliefs nor cognitive engagement alone are able to fully explain individuals' evaluation processes and outcomes.

The first individual difference variable that deserves mentioning is motivation. Students' uncertainty beliefs might influence their motivation to approach a task that requires the evaluation of conflicting scientific information (Muis & Foy, 2010), and motivated students might be more willing to maintain high levels of cognitive engagement even during such a complex task (Blumenfeld et al., 2006). Note that the present dissertation made a clear distinction between cognitive engagement and motivation. Cognitive engagement is related to the amount of mental resources that individuals tend to dedicate to certain kinds of tasks (general cognitive engagement) or invest while completing a task (situational cognitive engagement). This allocation of mental resources can then be channeled by motivational stances, metacognitive strategies, or epistemic beliefs (which were of course the focus of the present dissertation). Similarly, in the motivation literature, the concept of volition is used to explain how individuals direct the effort they invest in achieving learning goals (e.g., Corno, 1993).

The second variable that might explain individual differences in the reported results is self-regulation. Uncertainty beliefs have been associated with the self-regulated learning strategies students enact during a task (Muis, 2007). In turn, advanced self-regulated learning strategies could guide learners in how to distribute their cognitive engagement during a task (Baker, 1979; Wolters & Taylor, 2012). In this regard, future research may focus on effective self-regulated learning strategies that were beyond the scope of the present dissertation to further clarify the processes through which individuals evaluate scientific controversies (Greene, Copeland, Deekens, & Freed, 2018; Trevors et al., 2016). For example, the results of the present dissertation regarding uncertainty beliefs and cognitive engagement may be complemented by the investigation of individuals' sourcing strategies, focusing on how individuals detect and evaluate source information in order to assess which source can provide pertinent knowledge regarding a given scientific issue (e.g., Brand-Gruwel et al., 2017; Kammerer, Meier et al., 2016; Stadtler et al., 2013; Thomm & Bromme, 2016).

A third group of variables that might further explain the role of uncertainty beliefs and cognitive engagement in the evaluation of scientific controversies is related to individuals' tendency to embrace complex tasks, including need for cognition and intellectual values. Need for cognition refers to individuals' tendency to enjoy cognitively challenging tasks (Cacioppo, Petty, Feinstein, & Jarvis, 1996) and might be a potential moderator of the relation between uncertainty beliefs and cognitive engagement (see Kardash & Scholes, 1996). Similarly, Kuhn (2001) proposed that epistemic beliefs influence individuals' intellectual values, which in turn advise them on how much cognitive engagement is necessary to complete a task. The difference between intellectual values and need for cognition is that the former do not necessarily rate intellectual investment as enjoyable.

Finally, individuals' topic knowledge, topic interest, and prior topic-specific beliefs might have large effects on the interplay of uncertainty beliefs, cognitive engagement, and evaluation (even though the controversy-evaluation test used in the present dissertation was designed to be solved by "competent outsiders" without preconditions such as prior knowledge [Kramer et al., 2019]). Prior knowledge about the controversial issue at hand, as well as meta-knowledge about general principles of the scientific method, are likely to influence the amount of uncertainty individuals ascribe to a controversy, and, in turn, the amount of cognitive engagement they invest in integrating the conflicting positions (see Bromme et al., 2008; White, Collins, & Frederiksen, 2011; Zimmerman, 2000). Similarly, in addition to uncertainty beliefs and cognitive engagement, topic interest has also been shown to influence the way individuals interpret contradictory information (Mason & Boscolo, 2004; Mason, Gava, & Boldrin, 2008;

Renninger et al., 2018). Note that the present dissertation used a general measure of individuals' investigative interest but not topic-specific interest measures. Furthermore, Maier and Richter (2013) demonstrated that the consistency between individuals' prior beliefs and the information presented in a scientific controversy influences their comprehension of the controversial information. Therefore, given the high personal relevance of many controversial issues, these variables should be considered in the study of scientific controversies.

In summary, to further reduce the uncertainty of knowledge produced in the present dissertation, future studies may be encouraged to replicate and expand on the presented results by designing studies that allow for the examination of mutual influences between state-like and trait-like aspects of the investigated constructs, the integration of other dimensions of epistemic beliefs and engagement, and other relevant contextual and individual variables. Because neither uncertainty beliefs nor cognitive engagement are identical to the actual strategies individuals use when evaluating scientific controversies, it is advisable for future research to complement these measures with more explanatory variables that are relevant for individuals' second-hand evaluation (Bromme et al., 2013) of competing knowledge claims. However, researchers are cautioned not to further contribute to the current fragmentation in both epistemic belief and engagement research (Boekaerts, 2016; Mason & Bromme, 2010; Sandoval, 2016). For example, dozens of related terms that more or less synonymously describe individuals' epistemic beliefs already ghost through the literature (see Briell et al., 2011; Greene, Sandoval, & Bråten, 2016b). Hopefully, future research will contribute to more integration and coherence, for example, by building on and refining existing frameworks and by conducting more meta-analyses and literature reviews in order to handle the overflowing number of empirical studies. This would help keep the bigger picture in mind, despite all necessary differentiations.

5.3.2 Implications for practice

The three studies presented here demonstrated the influence of uncertainty beliefs, cognitive engagement, and their interplay for the evaluation of scientific controversies. These findings bear some important implications for practice. Given that these studies took place in a lab setting with a high degree of standardization, practical implications are less numerous and more tentative in comparison with implications for research. Still, some important conclusions can be drawn from the presented results. The following sections discuss implications of advanced uncertainty beliefs and pronounced cognitive engagement for learning and teaching science, followed by a more general discussion of the role of scientific controversies in science education and beyond.

Uncertainty beliefs

In science education, the uncertainty of knowledge has mostly been addressed in the context of the nature of science construct, which is more prevalent than epistemic beliefs in the science education literature. However, given the strong conceptual overlap between epistemic beliefs and nature of science (Deniz, 2017), the results of the present dissertation can inform practice on the role of uncertainty beliefs for successful reasoning and learning in science. Focusing on the "STEM" part of epistemic beliefs, addressing the uncertainty of knowledge in science and related fields is an important educational goal in itself (Kirch, 2012; Schroeder, McKeough, Graham, & Norris, 2018), and the present dissertation suggests that uncertainty beliefs can be beneficial for students in evaluating contradictory scientific knowledge claims. Hence, educators can be advised to foster uncertainty beliefs, which will likely help students overcome their misconceptions about science and develop a more elaborate understanding of scientific principles (Bell & Linn, 2002; Jehng et al., 1993; Kuhn & Weinstock, 2002; Lederman, 1992). Because uncertainty beliefs do not evolve automatically, mindful instructional approaches are necessary for them to grow roots in students' cognition (Hofer, 2001). Teaching practices that foster uncertainty beliefs also involve a different self-image of educators because the "removal of absolute certainty decenters authority with respect to knowledge, from teachers toward students" (Sandoval, 2005, p. 641). Focusing on the understanding of the tentative and evolving nature of scientific theories is therefore a means for fostering autonomous and critical thinking in students (Barzilai, Zohar, & Mor-Hagani, 2018; Duschl, 2008; Greene & Yu, 2016; Sandoval, 2005) as well lifelong learning (Bath & Smith, 2009) and personality development (Krettenauer, 2005). More specifically, teaching critical thinking by appreciating the uncertainty of knowledge might contribute to knowledge revision processes in the sense of conceptual change (Duschl & Gitomer, 1991; Mason, 2010; Muis & Duffy, 2013; Murphy & Alexander, 2016). Challenging their general and topic-specific uncertainty beliefs might help students process information they would not have considered otherwise, leading to more complex and differentiated knowledge representations. In the present dissertation, professed and enacted uncertainty beliefs were shown to affect how individuals think about scientific issues in a number of different topics and, more specifically, how well they were able to understand and evaluate plausible underlying reasons for scientific controversies. However, as stated above, fostering uncertainty beliefs in educational practice likely involves more variables than were examined in the present dissertation. For example, in a study focusing on knowledge revision in the topic of climate change, Mason et al. (2008) found that uncertainty beliefs were beneficial in conjunction with other variables such as topic interest. Educators who wish to promote students' uncertainty beliefs might refer to Bendixen and Rule's (2004) integrative personal epistemology model (see 1.3.2), which begins by challenging students' existing beliefs and results in the adoption of appropriate resolution strategies.

Furthermore, given the multifaceted nature of uncertainty beliefs as evidenced by the present dissertation, it is important for science educators to keep both students' professed and enacted uncertainty beliefs in mind. For example, explicit instruction regarding the nature of science might help students develop more stable and nuanced representations with respect to the uncertainty of scientific knowledge (i.e., professed uncertainty beliefs), whereas the teaching of reasoning skills and metacognitive strategies is needed to show students how to enact their uncertainty beliefs when they are confronted with controversial information (Barzilai & Chinn, 2018; Chinn et al., 2014; Sandoval et al., 2016). One way to uncover enacted uncertainty beliefs in science classrooms would be to have students explain what they thought about during a reasoning task, similar to the cued retrospective reports conducted in Study 3. Distinguishing between professed and enacted uncertainty beliefs might help educators to create more appropriate learning materials and prompt students to critically reflect on and develop their uncertainty beliefs. A guideline for how educators can frame instruction that is aimed at advancing uncertainty beliefs can be found in the AIR model of epistemic cognition (Chinn et al., 2014), which specifies criteria for how the proficient evaluation of inconsistent information might be fostered in terms of *a*ims, *i*deals, and *r*eliable processes. The aforementioned controversy on the harmfulness of diesel vehicles can be used as an example of how these three components might be implemented in science education. In this controversy, proponents from science, politics, and different interest groups in Germany put forward opposing claims about how harmful the exhaust emissions of diesel vehicles are and whether the existing benchmarks for exhaust levels should be changed. First, educators who discuss this issue in a science class could focus on the *aims* related to the opposing viewpoints and the value that is placed on them, for example, by emphasizing the different goals that industrial and environmental proponents pursue. Second, educators could expound on the epistemic *ideal* that benchmarks for exhaust levels are the result of complex decision-making processes involving the entirety of scientific evidence as well as political considerations and that individual studies are not sufficient to justify or question such benchmarks. Finally, regarding *reliable processes*, educators could discuss the advantages of science as an institutional practice over less reliable processes, such as the example of a professor communicating unfounded conclusions directly to the public (Köhler, 2019). Furthermore, teachers themselves can be role models for the advancement of students' uncertainty beliefs, given prior research showing a transmission from teachers' to students' beliefs (Song et al., 2007), emphasizing the importance of epistemic beliefs in teacher education (Buehl & Fives, 2016; Maggioni & Parkinson, 2008). Fostering advanced epistemic cognition as portrayed here is not only a means to promote students' reasoning skills in science, but it is also an intellectual virtue in itself (Hofer, 2017).

Uncertainty beliefs play a role not only in formal learning contexts but also in how science is communicated in the media. Do the results of the present dissertation imply that the uncertainty of research findings should be brought into the focus of science communication, given that scientific findings are often popularized and simplified in the media (Goldman & Bisanz, 2002)? Not necessarily. The evidence for whether communicating scientific uncertainty will, in turn, advance individuals' uncertainty beliefs has been inconsistent (cf. Flemming, Feinkohl, Cress, & Kimmerle, 2015, 2017; Retzbach & Maier, 2012). It is therefore the responsibility of all stakeholders, including the scientists who generate new knowledge, the media as gatekeepers that reprocess that knowledge, and the general public to find a trade-off between oversimplification (e.g., "Study X found absolute proof for phenomenon Z") and arbitrariness (e.g., "Study X and Study Y contradict each other, and both are equally valid") when dealing with the uncertainty of scientific knowledge (Bromme et al., 2018; Bromme & Jucks, 2018; Sinatra & Hofer, 2016). Furthermore, Sinatra and Hofer (2016) cautioned not to misuse the uncertain nature of scientific knowledge by presenting seemingly balanced perspectives for topics where there is (relative) consensus. For example, referring to the controversy on diesel vehicles, the current German minister of transport demanded a "holistic view" on the issue, implying that knowledge regarding the harmfulness of the emissions is less certain than it actually is (ARD Morgenmagazin, 2019). Scientifically literate citizens should be able to identify and evaluate more and less valid information sources, resulting in differentiated and flexible rather than dogmatic uncertainty beliefs (Britt et al., 2014; Hofer & Sinatra, 2010). To achieve this goal, modern media such as the Web can be used as an epistemological tool for knowledge integration (Mason et al., 2010b; Tsai, 2004). However, individuals must learn advanced strategies on how to integrate the myriad of information sources on the Web in order to cope with the challenges that our modern-day knowledge society poses (Goldman & Brand-Gruwel, 2018; Strømsø & Kammerer, 2016). Furthermore, scientific findings are often still communicated in written form, whereas scientific knowledge is increasingly perceived via alternative formats such as streaming videos (Welbourne & Grant, 2016), thus posing an additional challenge for the contemporary communication of scientific uncertainty.

Cognitive engagement

When educators foster advanced uncertainty beliefs as exemplified above, these beliefs can serve as a prerequisite for meaningful cognitive engagement. But on the other hand, promoting cognitive engagement in science without discussing the uncertainty of scientific knowledge is not likely to result in goal-directed learning and reasoning (Bendixen & Rule, 2004; Blumenfeld et al., 2006; Ferguson & Lunn Brownlee, 2018). Cognitive engagement, as conceptualized in the present dissertation, appears less amenable to direct instruction than uncertainty beliefs because it refers to the (general or situational) allocation of mental resources during science-related activities, which is more of a learning habit than teachable learning content. Rather, educators can build on instructional design research, demonstrating how tasks can be developed to elicit high levels of cognitive engagement without posing constraints on learners' available cognitive resources that are too large. In this regard, the malleability of cognitive engagement through task instruction was illustrated by Heijltjes, van Gog, Leppink, and Paas (2015), who demonstrated that critical thinking instructions resulted in increased situational cognitive engagement (as measured with the same single-item scale as used in Study 2 in the present dissertation; see Paas, 1992) when students completed a reasoning task. Additionally, educators can be advised to foster active cognitive engagement with contradictory documents by having students interact with the texts, for example, through annotations or other graphical representations (Barzilai et al., 2018; Chi & Wylie, 2014). However, educators should not only regard cognitive engagement as a predictor of student achievement. After successful task completion, educators can be advised to attribute students' success to invested effort and persistence (i.e., cognitive engagement) rather than ability (Goldman & Pellegrino, 2015), thereby increasing their self-efficacy. Beyond the design of particular tasks and their instructions, Wang and Eccles (2013) investigated the effect of teaching for relevance on cognitive engagement. Teaching for relevance frames the curriculum in a meaningful way, for example, by appealing to students' interests and autonomy, and results showed that these boundary conditions can enhance students' cognitive engagement. Similarly, general cognitive engagement had a high positive correlation with science interest in Study 2 of the present dissertation. Although the present dissertation did not include teacher-student interactions, prior research has suggested that the motivation teachers show can also have positive effects on students' cognitive engagement (Skinner & Belmont, 1993).

The present dissertation suggests that different aspects of cognitive engagement play a role in different aspects of the learning process, and educators need to be mindful about whether they want to address general or situational cognitive engagement to foster learning, or more specifically, to foster the competent evaluation of contradictory scientific information. For example, situational cognitive engagement was not related to the proficient evaluation of scientific controversies (cf. Heijltjes et al., 2015), but it has been shown to correspond with reading comprehension ability, and close attention on the side of educators is necessary to provide students with learning materials that do not exceed their reading skills. Addressing, utilizing, and evaluating scientific information is a complex task which also involves a number of contextual, cognitive, and motivational factors. In order to make student engagement more strategic and persistent, educators can draw on other factors that have been shown to guide and maintain cognitive engagement in prior research, for example, by motivating students or by explicitly discussing advanced self-regulatory skills (Blumenfeld et al., 2006; Corno & Mandinach, 1983; Pintrich & Schrauben, 1992). In this regard, fostering cognitive engagement might play a key role in initiating processes that can ultimately lead to a more elaborate understanding of science. The goal should then be to design and implement interventions based on well-established engagement models that help individuals to develop and maintain high levels of cognitive engagement in science.

Scientific controversies

From a broader perspective, the present dissertation recognizes the pivotal role of scientific controversies for instructional purposes and society as a whole. Understanding, evaluating, and integrating conflicting scientific information is an important feature of scientific thinking and reasoning in general (Aikenhead et al., 2011; Britt et al., 2014; Carey & Smith, 1993; Osborne, 2013). Conflicting evidence has long been a central aspect of science education (Bell & Linn, 2002; Chinn & Brewer, 1993; Hess, 2009; Schroeder et al., 2018), which continues to be relevant during higher education (Jehng et al., 1993). Not only can fostering uncertainty beliefs and cognitive engagement be used as a means for the proficient evaluation of scientific controversies. Being exposed to contradictory information can, in turn, guide readers’ attention toward different sources (Goldman & Scardamalia, 2013; Howitt & Wilson, 2018; Kammerer, Kalbfell, & Gerjets, 2016; Kienhues, Bromme, & Stahl, 2008; Kuhn & Weinstock, 2002) and thereby possibly advance their uncertainty beliefs (Barzilai & Ka’adan, 2017; Kienhues et al., 2016). Similarly, conflicting information has been used as an instructional tool to initiate conceptual change processes in science classrooms (Burbules & Linn, 1988; Dole & Sinatra, 1998; Sinatra & Chinn, 2012; Tabak & Weinstock, 2011; Wiley et al., 2018). However, using scientific controversies in educational settings requires a great deal of scaffolding and guided reflection in order to advise students on successful evaluation strategies to solve this complex task (Barzilai et al., 2018).

Whereas scientific controversies were evaluated in a relatively standardized solo setting in the present dissertation, some researchers have claimed that the full educational potential of scientific controversies can only unfold when individuals participate in authentic scientific practices and inquiry learning (Kuhn, 2010; Sandoval, 2005), for example, by enacting scientific discourse in the classroom. According to Sinatra et al. (2015), both epistemic beliefs and cognitive engagement can contribute to successful learning in authentic scientific practices. Similarly, Tabak and Weinstock (2008) assumed that authentic settings would promote less absolutist epistemic stances (i.e., weaker beliefs in certain knowledge). However, there is still debate on how effective such practices are in science instruction. In a study by Lin and Chan (2018), students participating in a knowledge building discourse developed more advanced epistemic beliefs than a comparison group. Similarly, Rosman, Mayer, Merk, and Kerwer (2019) found that university students receiving an intervention that consisted of active writing and the integration of conflicting information developed weaker absolutist stances than a control group. By contrast, McConney et al. (2014) found that participating in authentic scientific activities led to higher engagement but lower scientific literacy. Presumably, simply “doing” science is not enough to advance students’ understanding of science. Rather, students need to develop an understanding of how and why they can meaningfully engage in scientific practices (Berland et al., 2016). The difficult task for educators is to optimize science instruction so that students’ uncertainty beliefs and cognitive engagement are calibrated with the scientific practices of the respective knowledge domain (Ferguson & Lunn Brownlee, 2018). One potential strategy would be to problematize the concept of evidence when students are confronted with contradictory information (Duncan, Chinn, & Barzilai, 2018). Generally, fostering an advanced understanding of science would require avoiding questions that only strive for correct answers and focusing on open-ended questions instead (Barzilai et al., 2018; Hogan, 2000; Smart & Marshall, 2013). When knowledge is portrayed as unambiguous and fixed through a teacher’s questions, this might lead to less adaptive uncertainty beliefs in that teacher’s students and less cognitive engagement with scientific concepts. In the words of Muis (2007), “if students believe there is only one path to solution, then they may be more likely to give up more quickly or engage in less effort” (p. 180). A study by Elliott (2007) offers an example of an intervention that successfully fostered students’ uncertainty beliefs as well as their cognitive engagement by using science-related newspaper articles. It is the hope of the author of this dissertation that more future studies will investigate scientific controversies by focusing on antecedents of competent evaluation (e.g., uncertainty beliefs and cognitive engagement) that can inform educational practice on promising ways to foster students' understanding of science, their engagement with science, and their use of science for their academic and personal lives. Only then can they become scientifically literate individuals who can participate in our modern-day democratic knowledge society (Feinstein, 2011; Greene & Yu, 2016; Hess, 2008; Hofer & Sinatra, 2010).

5.4 Conclusion

Throughout the centuries, science has produced indispensable knowledge that has shaped the ways we live and think. Consequently, science is an integral part of modern societies. However, the proliferation of scientific knowledge has also led to increased controversy because nowadays, science pervades all aspects of individuals' lives, and with science being broadly accessible via modern media, scientific controversies have increased exponentially. Rather than the ideal that "reasonable people reasonably disagree" (King & Kitchener, 2004, p. 5), today's scientific controversies are characterized by knowledge claims that may not always be valid or justified. As a result, laypeople have both the privilege and the burden of having countless sources of information at hand, which are potentially inconsistent and contradictory. It is therefore more necessary than ever to identify factors that can help individuals in the evaluation of scientific controversies in order to make use of science for their professional and personal lives (Bromme et al., 2018; Sandoval et al., 2016).

In three empirical studies, this dissertation integrated research from two different traditions (i.e., epistemic beliefs and engagement) that are relevant for the evaluation of scientific controversies. Specifically, uncertainty beliefs and cognitive engagement were examined by applying innovative measurement approaches that integrate both offline and online data. Findings from Study 1 showed that uncertainty beliefs affect the evaluation of scientific controversies, partly mediated by cognitive engagement. In-depth analyses further revealed the interplay of trait-like and state-like aspects of these constructs. Study 2 provided insights into the differential functioning of general and situational cognitive engagement, and Study 3 demonstrated the interplay of professed and enacted uncertainty beliefs when individuals evaluate scientific controversies.

In the beginning of this dissertation, two problematic approaches to the uncertainty of scientific knowledge were pointed out. Whereas a growing group of individuals questions whether science can provide any certain answers to important questions, many scientists have participated in a countermovement, the so-called march for science, in which many (but not all) of them proclaimed that science can offer absolute and unambiguous truths. A prominent example of this view comes from biologist Richard Dawkins. During one of Dawkins' talks (Nuaim Sarh, 2013), a man from the audience asked whether the assumption that the scientific method leads to valid evidence is in itself an assumption that needs to be justified – a question that delves deep into the nature of science. However, Dawkins' answer simply referred to functional aspects of science, for example, stating that cars drive and planes fly, cumulating in an apodictic "It works, bitches." Arguably, the important question of today's time is not whether science as a whole “works” but rather how individuals’ epistemic understanding and engagement with science can contribute to a differentiated evaluation of controversial scientific information. The present dissertation offers one step toward answering this question.

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