

Which science disciplines are pertinent? –Impact of epistemological beliefs on students' choices

Porsch, Torsten & Bromme, Rainer, University of Muenster, Fliednerstraße 21, 48149 Muenster,
Email: t.porsch@uni-muenster.de, bromme@uni-muenster.de

Abstract: The growth of scientific and technological knowledge in modern societies has led to an increase of specialization of knowledge and expertise. Most socio-scientific issues are far too complex to be understood deeply by laypersons. From various disciplines we have to choose pertinent ones if we want to rely on expert advice. Epistemological beliefs might be helpful to cope with this challenge. Furthermore it is necessary to have realistic awareness of one's own fragmentary understanding and to avoid the "illusion of explanatory depth" (Rosenblit & Keil, 2002). In order to research on adults' capability to choose between disciplines who might be relevant for a science topic, N = 520 secondary school students were asked to choose, which of 22 scientific disciplines (e.g. math, geology, biology) should contribute to a book about tide and float. They were also asked to assess their own knowledge about the theme. Influence of epistemological beliefs has been tested by an epistemological sensitization in an experimental design. The epistemological sensitization significantly influences students' self-assessment of knowledge and discipline rating. Students with sophisticated epistemological beliefs were more critical about their own knowledge about tide and flow, chose significantly pertinent and -by tendency- potential pertinent disciplines more and declined non-pertinent disciplines more.

Introduction

Division of cognitive labor

The enormous growth and importance of scientific and technological knowledge in modern societies entail various consequences. Knowledge is unevenly distributed and we are laypersons in most knowledge domains. Dealing with various problems demand different and diversified knowledge backgrounds. Most socio-scientific issues (chemical additions to food, genetic engineering; Zeidler, Sadler, Applebaum & Callahan, 2009) are far too complex to be understood deeply by laypersons, but it is nevertheless necessary for laypersons to reason and to decide about these issues with regard to personal health or with regard to civic participation. Laypersons must rely on experts based on their own fragmentary understanding of such issues (Bromme, Kienhues & Porsch, 2009). Even children learn from the very beginning that they have to rely on others in order to get information, to answer a question, or to solve a problem (Bergstrom, Moehlmann, & Boyer, 2006). Children know that they can ask parents and peers if they need to know something. They differentiate who to trust (Harris, 2007), they are aware that people have different areas of expertise, and know how knowledge is clustered in the minds of others (Keil et al., 2008). For instance, in a study by Lutz and Keil (2002), 56 children of different age (3-, 4-, and 5-year-olds) had to judge which of two experts (a car mechanic or a doctor) would know more about a specific topic. Results show that the 4- and 5-year olds were able to attribute knowledge correctly based on scientific principles, whereas the 3-year olds performed better than chance merely on stereotypical role items. Even children have an early notion of the division of cognitive labor, they have an assumption which experts might know something about what. In the following we will call this knowledge about the "disciplines' pertinence" to certain issues.

An understanding of the pertinence of different knowledge fields to different issues must be based on an understanding of the structure of knowledge. Scientific knowledge has been developed in and is taught in academic disciplines, for example in school or at universities (Stevens, Wineburg, Herrenkohl, & Bell, 2005). We all grow up with and learn knowledge being structured into different disciplines. But not all issues and problems could be clearly and unambiguously assigned to one and only one discipline. Some issues are multi disciplinary and do not belong to only one discipline. Especially new, emerging problems and complex socio-scientific issues fell into the domain of several disciplines. Furthermore, the academic canon of disciplines is subject to continuous change. While it would be desirable if layperson would know who (which expert?) would be pertinent to which issue, it can be difficult asses which disciplines are more or less relevant for a theme. It is an open empirical question if secondary school students are able to identify disciplines which are pertinent to a complex scientific issue.

Epistemological beliefs

Research on epistemological beliefs, i.e. beliefs about the nature of knowledge and knowing, has expanded considerably in recent years (see, for overviews, Buehl & Alexander, 2001; Hofer & Pintrich, 1997, 2002). Epistemological beliefs include beliefs about the structure and variability of knowledge (Stahl &

Bromme, 2007). We can assume that someone conceiving knowledge as static, (if it has been found once it will not be changed anymore) and as a collection of clear, but separated facts that could be “found”, would have less elaborated ideas about the pertinence of disciplines to issues. Naïve or better to say “straightforward” epistemological beliefs might come along with a less elaborated awareness about the possibility to have different kinds of knowledge about the same issue (object of reference). We assume that such a person might have less well elaborated ideas about the pertinence of disciplines to topics, because she or he might tend to identify the knowledge with its objects of reference. In contrast, a person holding more sophisticated beliefs about knowledge (i.e. conceiving knowledge as dynamic and interrelated and more constructed than “found”) might have more elaborated ideas about the pertinence of disciplines to issues. Furthermore he or she might include more disciplines when asked which discipline might be pertinent to a certain topic. We expect therefore the following relationship between epistemological beliefs and judgments about the pertinence of disciplines to complex issues: Sophisticated epistemological beliefs go hand in hand with a better (more realistic) assessment of disciplines pertinence. Dealing with a complex scientific issue, sophisticated beliefs should foster the inclusion of various disciplines.

Knowledge self-concept

In informal settings it is necessary to have realistic metacognitive awareness of one’s own fragmentary understanding and to avoid the “illusion of explanatory depth” (Rosenblit & Keil, 2002). It is an open question if the self-assessed knowledge about the topic impacts on layperson’s assumptions about the pertinence of disciplines to complex scientific issues. Such an impact could be all the more probable as students self concept about their own knowledge differs between different school subjects. Even more, research on students’ self concepts has shown that students tend to overestimate the differences between their knowledge and abilities within different school subjects (Marsh & Hau, 2004). These findings of self-concept research argue for a cognitive and emotional impact of the disciplinary structure of school subjects on academic self concept, and as we conclude, they point to the possibility that the assessment of one’s own knowledge is relevant for judgments about the pertinence of disciplines to topics.

There is broad evidence for gender differences in self-concept (e.g. Marsh & Craven, 1997; Jacobs et al., 2002). Dealing with knowledge in school context boys tends to have higher self-concepts in subjects like math, whereas girls show a higher self-concept in language arts. Dealing with a complex scientific issue with a main focus on natural science, male students are supposed to have higher knowledge self-concepts. It is an open empirical question if the self-assessed knowledge about a theme moderates the rating of discipline’s pertinence and if this is also influenced by gender.

Research questions

In this study we address the following research questions: First, do students know which disciplines are pertinent? Based on the division of cognitive labor we expect that students are able to identify which disciplines are pertinent. Second, is the rating of discipline’s pertinence impacted by student’s epistemological beliefs? We expect that sophisticated epistemological beliefs foster the ability to assess discipline’s pertinence. Third, is the rating of discipline’s pertinence moderated by student’s knowledge self-concept? Furthermore, the influence of gender on knowledge self-concept and thereby also on pertinence ratings will also be considered.

Method

Procedure

Data collection was done on personal computers. During the session all students read an introduction text about tide and float. Students were randomly assigned to two sub-samples that received two versions of this introduction text about tide and float. Before and after reading the introduction text, an epistemological beliefs questionnaire has been conducted. Subsequently, students assessed their own knowledge about “tide and float”. In the main part of the study, students had to evaluate 22 disciplines regarding to their pertinence to the theme “tide and float”. The whole session took around 20 minutes for each student. Due to the computer supported session we have not to deal with missing data on the depending variables. When a question has not been answered, students have been pleased to do so before proceeding.

Participants

Secondary school students were randomly recruited during an open day at the university ($N = 520$). Mean age was around eighteen ($M = 17.95$; $SD = 1.01$). The majority of the participants was female (132 male, 382 female, 6 unstated).

Materials

Epistemological Beliefs Questionnaire

The success of the epistemological sensitization was determined by administering an instrument based on a semantic differential. The instrument was administered before and after reading the introduction text. The CAEB (Connotative Aspects of Epistemological Beliefs; Stahl & Bromme, 2007) consists of two scales of connotative adjective pairs: CAEB-texture measures beliefs about the structure and accuracy of knowledge on 10 items (sample item: “structured – unstructured”) and exhibited satisfactory reliability pre-instructionally (Cronbach’s $\alpha = .78$) as well as post-instructionally (Cronbach’s $\alpha = .85$). CAEB-variability measures beliefs about the stability and dynamics of knowledge on 7 items (sample item: “dynamic – static”) and exhibited medium reliability preinstructionally (Cronbach’s $\alpha = .64$) and satisfactory reliability post-instructionally (Cronbach’s $\alpha = .83$). The dimensions “texture” and “variability” are similar to the factors simplicity, structure and certainty from the Hofer model (Hofer & Pintrich, 1997, 2002) and the “source” dimension as described e.g. by Schommer (1990), but are named and conceptualized partly different. Texture encompasses beliefs about the structure and accuracy of knowledge. This factor includes beliefs from the dimensions “simplicity” and “source”, and from “certainty”. Variability encompasses beliefs about the stability and dynamics of knowledge. This dimension ranged from beliefs that knowledge is dynamic and flexible to beliefs that it is stabile and inflexible. This dimension mainly encompasses the dimension “certainty” but also the dimension “source”. Several studies have shown that the CAEB is a quite reliable and valid instrument (e.g. Stahl, Pieschl & Bromme, 2006; Pieschl, Bromme, Porsch & Stahl, 2008; Kienhues, Bromme & Stahl, 2008). For the measurement of epistemological beliefs in this study, it has been used in a topic related way, i.e. it had to be sensitive to the knowledge about the theme “tide and float” and students had to refer their answers just to their beliefs about knowledge from this theme. This takes into account, that such beliefs can be topic-specific (e.g. Trautwein & Lüdtke, 2007).

Introduction text

Ideas about pertinence of disciplines can be related to more and less sophisticated epistemological beliefs (see above). To consider these claims experimentally it is necessary to manipulate epistemological beliefs systematically: Two versions of an introduction text to “tide and float” were randomly administered to the students as an instructional intervention that we termed epistemological sensitization. In a recent study it was possible to successfully sensitize subjects reading science texts for an advanced epistemological stance by a comparable method (Kienhues, Bromme & Stahl, 2008). The two sub-samples did not differ with regard to age, gender, level of education, and school performance (measured by grades). One sub-sample ($N = 258$) read an introduction which was “straightforward” because it was enriched with statements that indicate a more structured and static view on the knowledge about tide and float (e.g., “models about tide and float fit well”; “water level forecasts are accurate even in the long run”). The other sub-sample ($N = 262$) received an introduction text that was enriched with comments on the epistemological nature of selected facts (e.g. detailing scientific controversies) and thus should elicit a more “sophisticated” view on the knowledge. Results show that the epistemological sensitization heavily impacted the ratings on the (Post-) CAEB-Questionnaire (repeated measure ANOVA for Texture: $F(1, 518) = 148.56$; $p < 0.00$, $\eta^2 = 0.22$ and Variability: $F(1, 518) = 301.94$; $p < 0.00$, $\eta^2 = 0.37$). The epistemological sensitization impacted the ratings into the assumed directions. For example, students in the straightforward instruction group rated their knowledge about tide and float as more structured and static in the Post-Questionnaire. In the sophisticated group students rated their knowledge as more unstructured and dynamic. Instruction groups are included as independent variables in subsequent analyses. For our research questions it is not important if this change is a fundamental and lasting modification of epistemological beliefs or a temporal effect on context-dependent epistemological resources (Hammer & Elby, 2003). We hereby acknowledge that our epistemological sensitization might only have changed epistemological beliefs during the session (in situ).

Knowledge self-assessment

Students rated their own knowledge about “tide and float” on 5 Items (e.g.: “I already know very much about tide and float” or “There is not much more, that I can learn about tide and float” (reversed)). Students answered each item on a 5-point-Likert-scale (from “I totally disagree” to “I totally agree”). The scale exhibited satisfactory reliability (Cronbach’s $\alpha = .84$). Students rated their knowledge above mean ($M = 3.08$; $SD = 0.88$). The individual results of the knowledge self-assessment scale are admitted in further analysis. Due to the above mentioned results, gender will be included as an independent variable in subsequent analyses.

Discipline evaluation

To measure how students assess the pertinence to difference disciplines, the following scenario was established. We told the students that all the knowledge about tide and float is going to be gathered in a book. They had to decide which disciplines should contribute to this book. Each discipline had to be rated on a 5-point-Likert-scale (from “should absolutely not contribute” (1) to “should absolutely contribute”(5)). The result of the discipline evaluation is admitted in further analysis as a depended variable. Twenty two different

disciplines were listed (randomized for every student): forestry, meteorology, geo science, life sciences, landscape ecology, information technology, electro technology, business informatics, e-business, information management, physics, chemistry, biology, math, medicine, orthopedagogy, museology, astronomy, oceanography, engineering, geology, and hydrology. The disciplines have been collected from the domains “environment”, “general knowledge”, “computer” and “health”. There are some clearly pertinent disciplines (e.g. oceanography) but there are also cases where the relevance for the topic is less obvious.

Results

Do students know which disciplines are pertinent?

This question was investigated by using an external criterion. Disciplines' pertinence is not as obvious as it seems to be (see above). One way to consider the gradual pertinence of several disciplines to one theme, is to embrace the public perception. The combined appearance of theme and discipline in newspapers, journals and web databases provides an indication of pertinence. This approach is based on the assumption, that disciplines are more often mentioned together with a specific theme, if they are pertinent ones. The following approach uses a methodology transferred from the calibration paradigm (Nelson & Dunlosky, 1991): First, a measure for quality of the students' discipline ratings was determined. Objective values were computed from the relative frequency of the co-occurrence of the theme (“tide and float”) and each discipline (“e.g. physics”) within Lexis Nexis, a large text data base. By reason, that the co-occurrence is just a frequency's subset of the theme and of the discipline, the value was divided by the sum of the overall frequencies. The strength of association between theme and each discipline has been used as an indicator of “objective” pertinence of the discipline to the topic. (Note that it is only ‘objective’ in the sense that it is reflected in the thousands of documents which make up the data base, and that we use it here as the norm for a comparison with of our students' assessments). The systematic relationship between student's discipline ratings and the objective value was determined by computing within-subject Goodman-Kruskal Gamma correlations (G). These were subsequently Z-transformed into indices. Median of indices overall students was $G = 0.58$ ($t(518) = 16.21, p < .001$).

The results can also be considered in a descriptive manner. Student's ratings differed between disciplines (Figure 1). An empirical trichotomy of the data gets obvious. Seven disciplines (oceanography, physics, astronomy, geo science, geology, life sciences, biology) with a mean rating above $M = 4.0$ are highly associated with the theme. The pertinence of five disciplines (meteorology, math, landscape ecology, hydrology, chemistry) is much more graded ($3.0 < \text{mean rating } M < 4.0$). All other disciplines are mostly declined (mean rating $M < 2.0$). To sum up, student's ratings correlate significantly with the associations of disciplines and theme in a text data base. Furthermore, students clearly identify disciplines which have to contribute, maybe should contribute and definitely should not contribute.

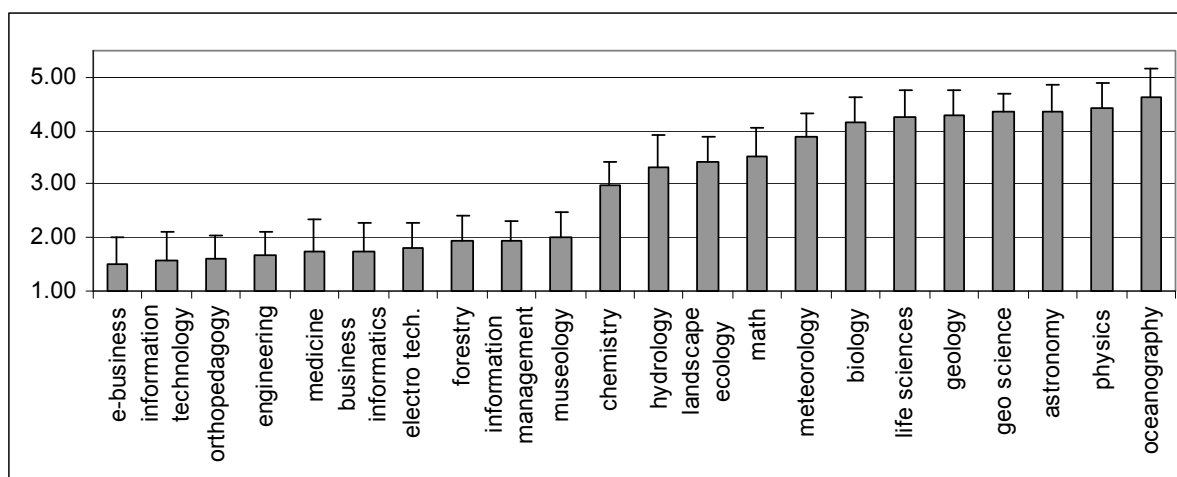


Figure 1. This figure visualizes the mean discipline ratings.

Are discipline ratings impacted by epistemological beliefs and knowledge self-assessment?

In order to answer this question the experimental groups (straightforward versus sophisticated instruction text) as well as gender were included as dichotomous factors in a measurement model (linear regression). To account for the trichotomy in discipline ratings three dependent variables have been computed: “Mean rating of pertinent

disciplines (RD)” ($N = 7$, $M = 4.35$, $SD = 0.49$), “Mean rating of disciplines with graded pertinence (GD)” ($N = 5$, $M = 3.42$, $SD = 0.63$) and “Mean rating of non-pertinent disciplines (ND)” ($N = 10$, $M = 1.76$, $SD = 0.55$). Interactions between errors of these three variables (RD, GD and ND) are accepted in the model. Furthermore, the knowledge self-assessment scale (KSA) was included in the measurement model. Fit indices indicate a sufficient model fit (Byrne, 2001). Relative chi-square ($\chi^2/df = 1.57$) and the comparative fit index ($CFI = 0.98$) exhibit an acceptable fit between the hypothetical model and the sample data as well as the point estimate of the root mean square error of approximation ($RMSEA = 0.03$). No significant interactions between independent variables (experimental group and gender) have been found. As shown in Figure 2, introduction text ($r = -.42$, $p < 0.001$) and gender ($r = -.29$, $p = 0.003$) significantly impacted knowledge self-assessment (KSA). Students who read the sophisticated introduction and female students significantly stated to know less about “tide and float”. The independent variable “introduction text” also impacted significantly the “Mean rating of pertinent disciplines (RD)” ($r = .27$, $p = 0.002$). Students in the group with the sophisticated introduction text agree significantly stronger to the pertinent disciplines (RD). By tendency, students who read the sophisticated introduction agree also stronger to the disciplines with graded pertinence (GD) ($r = .17$, $p = 0.058$) and decline non-pertinent disciplines (ND) more ($r = -.05$, $p = \text{n.s.}$). No relation between knowledge self-assessment (KSA) and discipline rating as well as between gender and discipline rating has been found.

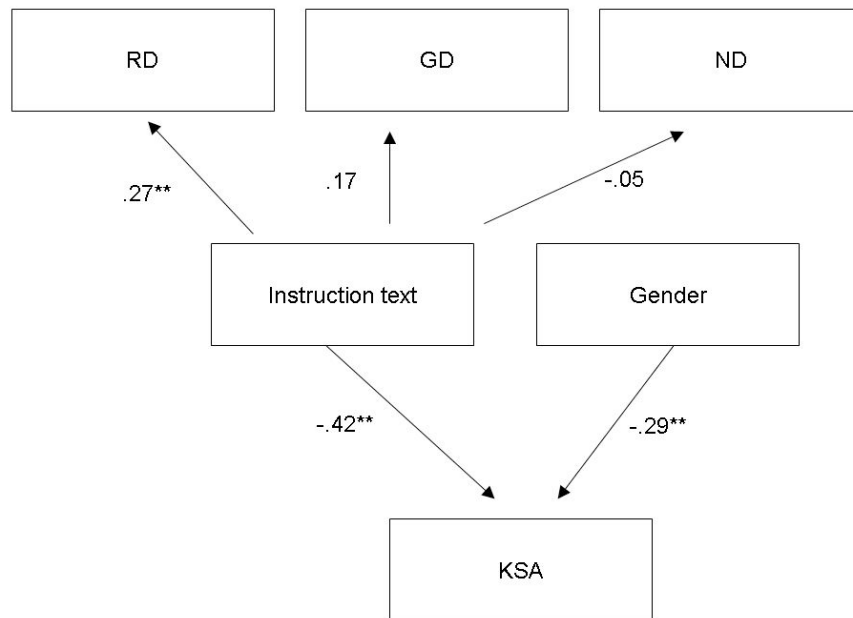


Figure 2. This figure visualizes the results of the measurement model ($N = 520$). (RD = Mean rating of pertinent disciplines, GD = Mean rating of disciplines with graded pertinence, ND = Mean rating of non-pertinent disciplines, KSA = knowledge self-assessment).

Discussion

To rely on others gets increasingly important in modern society (Bromme, Kienhues & Porsch, 2009). A realistic view on own knowledge as well as knowledge about pertinence of disciplines are helpful requirements in academic and informal settings. Results of this study indicate that students are aware of discipline’s pertinence and know which disciplines are pertinent to the theme “tide and float”. They are able to assess disciplines’ pertinence in a meaningful way. Student’s ratings are significantly correlated with findings in a large text data base. The pertinence ratings of the used disciplines to “tide and float”, are concordant with the appearance of the combination of disciplines and theme in newspapers, journals and web databases. The descriptive consideration of the data reveals that next to pertinent and non-pertinent disciplines, some disciplines exhibit a graded pertinence to the theme. Empirically three groups of pertinence (pertinent disciplines, disciplines with graded pertinence and non-pertinent disciplines) could be established. The discipline pertinence ratings of these groups are partly explained by the epistemological sensitization. The results show that all students assume that there are some disciplines which are pertinent (oceanography, physics, astronomy, geo science, geology, life sciences, biology) or graded pertinent (meteorology, math, landscape ecology, hydrology,

chemistry). But students who read the sophisticated introduction text agree stronger to the pertinent and graded pertinent disciplines. Students who read the straightforward introduction text preferred these disciplines less. This result indicates that students in the sophisticated sensitization group have more elaborated ideas about the pertinence of disciplines: They tend to include the pertinent and graded pertinent disciplines more when asked which discipline might be pertinent to a certain topic. The given topic is a quite multidisciplinary one. Students with strong ideas of the connectedness and variability of knowledge might tend to transfer their beliefs on ideas about the pertinence of disciplines. The results indicate that students are able to do this in a meaningful matter. Instead of assuming a general pertinence of all disciplines, students with more sophisticated beliefs made a better choice. The sophisticated epistemological sensitization induces a more differentiated choice between the disciplines. All disciplines which seemed, even only rudimentarily, pertinent were appraised higher.

The expected influence of the knowledge self-concept on disciplines' pertinence rating has not been found. Students concept about own knowledge about the topic doesn't impact their ability to assign pertinent disciplines to the topic. We conclude (cautiously because it is a speculation based on the lack of empirical relationship) that ideas about who knows what (knowledge about the division of cognitive labor) are relatively independent from knowledge about the reference issue itself. Our cautious conclusion is in line with Keil et al, (2008) who reported awareness about the division of cognitive labor held by young children who clearly lack deep knowledge about the reference issue.

Gender influences the knowledge self-assessment independent from epistemological beliefs. Female students stated to know less. This result is in line with findings about gender specific self concept in academic contexts (e.g. Shaalvik & Rankin, 1990; Marsh & Craven, 1997; Jacobs et al., 2002). The theme "tide and float" is contextualized in school in the subjects as "physics" or "geography". Gender differences in self-concept in context of these "natural scientific" subjects are as expected. But these differences did not impact the rating of discipline's pertinence. Neither knowledge self-assessment nor gender itself has impacted student's choices.

The analyses uncovered further results. With regard to the content used here, the sophisticated epistemological sensitization causes students to assess more cautiously their own knowledge about the issue at stake. But this is not necessarily a misjudgment. Their knowledge self-assessment could be simply more realistic. Even if they have already superficial knowledge about the theme, most of the students have not dealt with the underlying mechanisms before. With regard to the research by Rosenblit & Keil (2002), we assume that the straightforward sensitization contributes to an "illusion of explanatory depth". In this study, the confrontation with epistemological uncertainties ("texture" and "variability") e.g. by detailing scientific controversies, might have helped the students to relativize their own knowledge about "tide and float" in a realistic way. Further studies should also take qualitative methods into account to provide an insight into why more sophisticated epistemological views make students more critical about their own knowledge.

There are, however, some limitations of this study: We did not capture underlying reasons for preferring a discipline but rather ask for student's spontaneous judgments. Additionally, we acknowledge that our epistemological sensitization might not have resulted in a sustained change of the students' epistemological beliefs. Within this study we focused on the relationship between epistemological views and pertinence assessments and the question, if the epistemological views which we have established within our experiment will be stable or not can be postponed to further studies. Nevertheless, our finding that it is possible to induce such an epistemological sensitization by a rather sparse intervention has interesting educational implications. The intervention which was used here for experimental reasons could be also used for educational aims. Of course, such sensitization might only work with specific topics. The implementation of the epistemological sensitization has to be tested further to use it in more real life settings (e.g. classrooms and textbooks) with more diverse populations. In everyday problem solving and decision making it is a quite common task to decide about disciplines pertinence in context of mostly unknown knowledge topics, but the capabilities which are necessary here have not been researched intensively so far. While our results are clearly confined to our sample (secondary school students) they do nevertheless demonstrate how such capabilities could be studied.

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