The Interplay of Domain-Specific and Domain-General Factors in Scientific Reasoning and Argumentation

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Abstract: This symposium raises the issue of the role of domain-general factors in scientific reasoning and argumentation tasks. The contributions cover conceptual problems concerning the interplay of general and specific elements in scientific reasoning, methodological requirements and existing research paradigms for investigating the role of cross-domain factors in scientific reasoning and argumentation tasks, limitations of domain-general epistemic criteria in the context of evaluating competing explanations and evidence, and experimental evidence exploring the limits of domain-generality in the context of interventions designed to foster scientific reasoning. The symposium includes a technology-supported interactive discussion with the audience.

Introduction

Argumentation and scientific reasoning are often included among the crucial skills that students need in order to master the challenges of a knowledge society in the 21st century. These skills are typically conceived of as broadly applicable and largely domain-independent.

However, the idea of cross-domain skills has been challenged more generally from several directions. First, research in personality psychology has showcased so-called "general cognitive abilities" (i. e. intelligence) as the single domain-independent factor in the explanation of performance variation among persons in cognitive tasks across fields, including scientific reasoning and argumentation. Second, research originating from cognitive psychology has emphasized the amount and quality of highly domain-specific experiences as a major explanatory variable for skilled performance. In particular, expertise research has provided strong evidence for the dominating role of years of deliberate practice for developing highly domain-specific excellence (Ericsson, 2006). Third, the situated cognition approach has advanced the idea that knowledge is tied to activities in specific contexts and cannot easily be transferred to different activities (e. g., Greeno, 1998). This symposium takes on the issue of the existence and the role of domain-general factors for performance in scientific reasoning and argumentation tasks. A particular focus will be on the relationship and the interplay of domain-general and domain-specific factors in these tasks.

In the first contribution, Jonathan Osborn questions the tenability of scientific reasoning as domain-general. As further problems he identifies the failure to take the role of knowledge in scientific reasoning into account, a lack of reconciliation of partly complementary perspectives of researchers from different disciplines, as well as a lack of focus on critique as an important component of scientific reasoning.

Second, Christof Wecker, Andreas Hetmanek, and Frank Fischer first discuss the methodological requirements for empirical research that purports to demonstrate or disprove the existence of cross-domain skills of scientific reasoning and argumentation. Then they identify three research paradigms and review exemplary studies from each of them, including research of their own, which all suggest that cross-domain skills may actually play a role in scientific reasoning and argumentation.

Third, Clark Chinn, Ravit Golan Duncan, and Ronald Rinehart set out to theoretically explore the interplay of domain-general and domain-specific factors, and particularly, of the ways in which domain-general knowledge can and cannot be used across domains or topics depending on the domain-specific knowledge available. Drawing on findings from the PRACCIS (Promoting Reasoning and Conceptual Change in Science) project, they show how students both are able to develop sets of epistemic criteria that they attempt to apply across domains, and struggle actually applying these criteria across domains. Failure to identify referents for the criteria, referent misidentification, and narrow knowledge are identified as the major obstacles.

In the fourth contribution, Stephanie Siler and David Klahr turn to the issue of how domain-general skills are learned, and to the role of domain-specific examples in this process. In an experimental study they could show that, across the board, students made the least progress if they first evaluated experiments that were represented in an abstract fashion (no specific values for independent variables mentioned) and then experiments that were represented in a concrete fashion (specific values of independent variables mentioned). Younger and lower-ability students showed better transfer in an all-concrete condition than in a concrete-fading condition. Domain-specific information appears to be critical for acquiring domain-general skills.

Finally, the discussant William Sandoval will identify specific and common issues in the different contributions, bring in his own perspective on the topic, and start the discussion with the audience. To facilitate interaction with the audience, we will use Web-based audience response technology and ask the audience to write comments and reactions via their smart phones or computers during the individual presentations. One of the co-authors of this symposium will monitor contributions from the audience and provide a summary of the reactions directly after the presentation. In addition, one or two issues that seem specifically thought-provoking may be highlighted and the presenter may be asked to respond to it. In addition, the discussant will raise more general, overarching issues, to which every presenter can briefly respond. The audience will again be invited to contribute further, more overarching questions and arguments.

Teaching Scientific Reasoning: The Ineluctable in Search of the Ineffable?

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Ever since its inception, one justification for science education has been that it might educate the neophyte student in the highly-valued, disciplinary habits of mind of the scientist (DeBoer, 1991; Dewey, 1916; Layton, 1973; Turner, 1927). In contemporary society where information is readily available, such arguments have become more pre-eminent. Hill (2008), for instance, has argued that the societies that sustain their competitive edge in the coming decades will be 'post-scientific' societies. In such a society, highly valued skills will be the ability to draw on a range of disciplinary knowledge, to think creatively and to evaluate new ideas in a critical, reflective and rational manner. Employers will require individuals who, while having a core understanding of scientific and technical principles, have the ability to communicate and synthesize knowledge in an original manner. Similar arguments can be found in the recent NRC (2012) report which argues that it is important to develop three domains of competence – the cognitive, the intrapersonal, and the interpersonal. Gilbert puts it even more straightforwardly arguing that 'in a world where there is an oversupply of information, the ability to make sense of information is now the scarce resource' (Gilbert, 2005). Central to developing students' ability to undertake the cognitive process of complex reasoning is the ability to think critically and analytically, tackle non-routine problems, and construct and evaluate evidence-based arguments. In the case of science education, then, it is important to 'be certain that we emphasize what we want, for we shall surely get what we emphasize' (Hill, 2008). However, science education has suffered from a lack of clarity about 'what we want' and how to build student competency with scientific reasoning. Drawing on a historical analysis this paper identifies four problems have confounded the field each of which is elaborated beneath. The paper then offers a model of scientific reasoning which addresses each of these concerns.

Problem 1: The Disjuncture between Domain-Specific and Domain-General Conceptions of Scientific Reasoning

The first problem is a product of the failure to identify the *domain specific* and disciplinary nature of scientific reasoning. Whilst this may seem self-evident to science educators, many attempts to define scientific reasoning have emphasized scientific reasoning as a *domain general* concept. One version of this is seen among psychologists who commonly take a 'nothing-special view' (Simon, 1966) arguing that general reasoning abilities can account for the main characteristics of scientific reasoning, and that these are more important as they are *transferable*. Klahr and Simon (1999), for example, acknowledge that domain-specific aspects are the basis for 'strong methods' within the sciences, but claim that these only have limited value because they apply to well-defined contexts and problems. Instead, they contend that, when scientists move into new areas and meet ill-defined problems, general strategies or 'weak methods' are the most important forms of reasoning.

The contrary argument, however, has been made both within psychology and science education. Perkins and Salomon (1989), for instance, made a seminal argument that 'general heuristics that fail to make contact with a rich domain-specific knowledge base are weak' and that 'a domain-specific knowledge base without general heuristics…is brittle' (p. 24). Within science education, Passmore and Stewart (2002), for instance, have argued that 'scientific practice is discipline specific' (p. 187). Likewise, Sandoval and Morrison (2003) conclude from their analysis of student explanations of Galapagos data 'that epistemic and conceptual understanding are tightly interrelated.' (p. 48)

Defining scientific reasoning either as domain general cognitive skill is both flawed and unsustainable. It is flawed because it misrepresents the nature of scientific reasoning as, while individuals in everyday situations may use reasoning akin to that of scientists, such forms of reasoning can not be used to *define* what is distinct about scientific reasoning. Similarly, arguments for the value of teaching domain-general reasoning within science are unsustainable because general reasoning does not *have to* be taught in science. A logical consequence of this view is that science education is in need of a conception for scientific reasoning that identifies its *domain specific* characteristics more uniquely.

Problem 2: The Failure to Identify the Role of Knowledge in Scientific Reasoning

This problem has challenged cognitive psychology since the late 1950s, when researchers made provocative comments about reasoning skills being *knowledge-independent*, or, as expressed by Inhelder and Piaget (1958) as a facility which was to be seen as 'liberated from particular contents'. While most psychologists today admit that reasoning is knowledge-dependent (Zimmerman, 2007), many have continued to study domain-general reasoning processes in *knowledge-lean* tasks (problem 1).

From a disciplinary perspective, such a position is not satisfactory as domain-specific knowledge should be at the heart of scientific reasoning. What, for instance, are the domain-specific entities used by the individual when reasoning within the domain? Undoubtedly, a factor that has changed over the past six decades is the development in our understanding of what we mean by knowledge – a development that can be illustrated by the changes that have occurred in Bloom's (1956) taxonomy of cognitive processes when compared to the revised version offered by Anderson & Krathwohl (2001). These authors split reasoning into two dimensions, a knowledge dimension and a cognitive process dimension, and use not one but four categories to describe their knowledge dimension: factual knowledge, conceptual knowledge, procedural knowledge and metacognitive knowledge. Likewise, Li and Shavelson (2001) have used a similar framework splitting knowledge into declarative knowledge (knowing what), procedural knowledge (knowing how), schematic knowledge (knowing why), and strategic knowledge (knowing when, where, how knowledge applies) – a perspective that was influential in developing the NAEP 2009 framework for assessment in science. The common point in these and other examples is that they alter the way we conceptualize the relationship between knowledge and reasoning. That is, what used to be explained as a generic 'reasoning skill' linked only weakly to a body of undifferentiated knowledge is now dependent on a set of distinctive aspects of domain-specific knowledge of 'what we know', 'how we know' and 'why it happens'.

Problem 3: The Differing Perspectives of Psychologists and Philosophers

In academic research, the most conspicuous difference in accounts of scientific reasoning is between psychological and philosophical definitions. Psychologists approach the study of reasoning in a descriptive way with a focus on cognitive processes and abilities. Sociologists, likewise, are equally descriptive but their focus is on the social practices that enable the constitution of new knowledge. Philosophers in contrast take a normative perspective focusing more on the epistemological principles and values intrinsic to the reasoning. In one sense psychologists are more concerned with *how* someone reasons, while philosophers and sociologists seek to understand *why* they reason as they do and how they justify scientific belief, albeit from very different perspectives (Bailin & Siegel, 2003). While philosophers, sociologists and psychologists may find their differences tolerable, educators cannot. As Millar and Driver (1987) have shown, any educational 'definition' of scientific reasoning has to give a 'correct' picture of science in that it: first adequately represents the common reasoning practices of science; second, aligns with current thinking in the learning sciences; and third, 'works' in the sense that it does not place unreasonable expectations on either students or teachers. The need for a 'correct picture' is justified because teaching of scientific reasoning is also teaching *about* science, and it 'seems unwise, to say the least, to develop a rationale for school science upon a view of science which is seriously at odds with current thinking' (p. 45). However, in the history of science education rarely have the insights offered by philosophy, sociology and psychology been brought together. Consequently, 'merging' these perspectives on scientific reasoning to create a rationale that informs educational practice has been a goal of recent work – the aspiration being to develop a conception that is more workable in the classroom.

Problem 4: The Absence of Critique

The fourth problem is the failure to recognize the role and value of critique in the construction of knowledge. The practice of science requires a dialectic between construction and critique (Ford, 2008). The two activities are thus mutually dependent and any account of scientific reasoning to be offered in the classroom must incorporate a means of acknowledging the centrality of critique. The argument here is that ideas are rarely considered in isolation and that a Bayesian account (Howson & Urbach, 2006) of reasoning offers a better model of scientific reasoning. For instance, persuading a student of the validity of the scientific account is as much a task of demonstrating why alternate ideas are flawed as one of demonstrating why the scientific idea might be right and adjusting the balance of their beliefs. Developing any understanding of the centrality to critique to scientific reasoning requires it to be a common feature of the science classroom. However, the dominance of construction means that it is almost an absent feature of common pedagogic practice. One consequence, as empirical evidence from our work on developing a learning progression for argumentation shows which will be presented, is that students find engaging in critique harder than engaging in construction (Osborne et al., 2013).

To address all four of these problems, a model for scientific reasoning is proposed. This seeks to combine both the philosophical model of reasoning presented by Giere et al. (2006), and the psychological model of science as a process dependent on working in two search spaces developed by Klahr and Dunbar (1988). This model emphasizes three fundamental spheres of activity which require scientific reasoning: the development of theoretical models and hypotheses (developing explanations and solutions); the testing of hypotheses against using data gathered from the 'real world' (investigation); and the coordination and evaluation of the outcomes from these two domains of activity (evaluating).

The most coherent account of the nature of scientific reasoning emerges from those historians who offer a cognitive history of science (Crombie, 1994, Netz, 1999) that identifies 6 distinctive forms of reasoning *within science* . Crombie argues that these styles of reasoning have no foundation – they are just how we reason in science and are an emergent feature of the socio-cultural context where they were first developed. Each of these forms of reasoning brings into being a set of ontic, procedural and epistemic entities that are required to perform the reasoning – each of which are *domain specific*. In this presentation, it is argued that the recognition of the forms of reasoning intrinsic to science, and the spheres of activity in which they are conducted, provides not only a better argument for what should be taught but also how it should be taught.

Do Cross-Domain Skills of Scientific Reasoning and Argumentation Exist?

Christof Wecker, Andreas Hetmanek, Frank Fischer, Ludwig-Maximilians-Universität München

In this symposium, the present contribution has the function of (1) specifying the requirements that need to be imposed on empirical evidence in favour of the existence of cross-domain skills such as the skills of argumentation or scientific reasoning, (2) discussing research, including our own, from three different paradigms that may provide evidence in favour of the existence of cross-domain skills, and (3) formulating consequences and directions for future research.

Requirements for Empirical Evidence in Favour of Cross-Domain Skills

To specify the requirements that need to be imposed on empirical evidence in favour of the existence of cross-domain skills, we need to consider the "logic of skills": "Skill" (the terms "competence", "ability" could be used synonymously) is a dispositional concept (Heider, 1958, ch. 4), i. e. the property of a person, which it describes, is manifested in a specific kind of performance in specific situations. For instance, to state that *somebody has the skill to perform a hypothesis test* means that he or she will manage to conduct an adequate hypothesis test if he or she is motivated and has the opportunity (including that appropriate tools and materials are available) to do so (cf. Heider, 1958, ch. 4). Thus, skill is an explanatory factor of performance beyond opportunity and motivation.

However, the skill component involved in the explanation of a certain kind of performance is not a monolithic entity that is tied to the particular kind of action in a one-to-one fashion; the quality of hypothesis testing performed by different persons may differ if one person (a) has more knowledge about the topic than the other person; (b) excels on almost any cognitive tasks while the other struggles with most cognitive challenges; (c) has better skills in operations that are conducted during hypothesis testing. In other words, given the same motivation and opportunity, performance varies as a function of domain-specific knowledge, intelligence, and skills that are not tied to a particular domain, i. e. cross-domain skills.

Ironically, each of the explanatory factors of performance except one has its advocates in psychological research: Domain-specific knowledge (expertise research) and intelligence (differential psychology), but also motivation (motivational psychology) and opportunity (situated cognition, socio-cultural approach, activity theory), are all well respected factors in explaining performance. The only factor that has remained elusive and the existence of which has been questioned repeatedly are cross-domain skills. A reason for this may be that so far research has failed to provide a compelling account for explaining this factor itself, as compared to the accounts that have been suggested for domain-specific knowledge (e. g. as individual chunks or schemata within a simulation framework for human cognitive architecture, see, e. g., Anderson & Lebiere, 1998) and intelligence (e. g. as certain aspects of working memory capacity, see, e. g., Kyllonen & Christal, 1990). At the same time, the criteria for empirically demonstrating the existence of cross-domain skills are completely parallel to those for each of the other factors. Hence, the question whether cross-domain skills of scientific reasoning and argumentation exist can be operationalized – with increasing specificity – in the following ways:

Are there any data showing that

(i) some people systematically outperform other people with identical opportunity, motivation, intelligence, and domain-specific knowledge in scientific reasoning or argumentation tasks?
(ii) some people systematically outperform other people with identical opportunity, motivation, intelligence, and domain-specific knowledge in scientific reasoning or argumentation tasks from at least two different domains?
(iii) the degree to which some people systematically outperform other people with identical opportunity, motivation, intelligence, and domain-specific knowledge on a scientific reasoning or argumentation task from one specific domain is correlated with certain "strategic" knowledge that does not contain any reference to specific knowledge from the domain of the task?

A positive answer to the first question would imply that performance is not explained by intelligence and domain-specific knowledge alone. A positive answer to the second question would imply that the explanatory factor beyond intelligence and domain-specific-knowledge is in fact not tied to a particular domain. A positive answer to the third question would involve insights about the nature of the strategic knowledge underlying a particular cross-domain skill.

Research Evidence from Three Paradigms in Favour of the Existence of Cross-Domain Skills of Argumentation and Scientific Reasoning

We can conceive of three research paradigms that can provide evidence pertinent to the question of whether there are any cross-domain skills, in particular with respect to argumentation and scientific reasoning:

(i) research on expert performance in a domain that falls outside of their particular area of expertise but still has some similarities to it,
(ii) well-controlled experimental studies about interventions demonstrating effects on transfer tasks from a different domain than the one used during the interventions themselves, and
(iii) correlational studies on predictors of performance controlling for competing explanatory factors and trying to explain variance in performance by means of cross-domain dispositions or, more specifically, skills.

In the following, we briefly discuss some exemplary findings from these three paradigms before presenting the findings from our own research that can be subsumed under the correlational approach.

Expert Studies

Schunn and Anderson (1999) found that in scientific reasoning tasks such as experimental design and analysis, psychologists from an area unrelated to the specific tasks by far outperformed undergraduates despite similar levels of domain-specific expertise. This finding is incompatible with the view that performance differences in scientific reasoning can be explained by highly domain-specific expertise.

Transfer Studies

Klahr and colleagues have repeatedly shown in strong experimental designs that certain aspects of scientific reasoning – i. e., the control of variables strategy – can be efficiently trained using an explicit teaching approach, and that typically learners from the training conditions by far outperform learners from control groups on control of variable tasks from topical areas that were not covered in the training phase (e. g., Klahr & Nigam, 2004). These findings are incompatible with the position that domain-specific knowledge and intelligence alone can account for performance differences in scientific reasoning.

Correlational Studies

Stanovich and West (1997) showed that individual differences in college students' performance in evaluating arguments concerning real-life situations are reliably linked not only to individual differences in intelligence, but also to a habit of actively open-minded thinking: Actively open-minded thinking remained a significant predictor even after individual differences in intelligence had been partialled out (Stanovich & West, 1997, p. 342). These kinds of analyses show that cross-domain dispositions can be a relevant explanatory factor. However, the authors characterized this further explanatory factor as a habit rather than as a skill or some kind of strategic knowledge underlying a cross-domain skill.

To generate evidence demonstrating that strategic knowledge can be an important factor (see (3) above), we conducted a study with a similar design, but with an additional cross-domain strategic knowledge factor to bind unexplained variance. In particular, we wanted to provide evidence for the role of argumentation strategy knowledge as a further explanatory factor for performance in argumentation tasks while controlling for general cognitive abilities and domain-specific knowledge. The participants in this study were 123 university students who completed online tests for the three predictor variables and produced written arguments in favour of their opinion concerning energy supply. Using structural equation modeling, we were able to show that after controlling for general cognitive abilities and domain-specific knowledge, argumentation strategy knowledge still significantly contributes to the explanation of performance variation in argumentation tasks. Furthermore, multiple-group analysis revealed that this relation between argumentation strategy knowledge and performance in argumentation tasks holds only for learners with domain-specific knowledge above a certain minimal threshold, which is in line with the idea that cross-domain skills such as argumentation strategies require a certain minimal amount of domain-specific knowledge upon which they can operate (cf. Alexander & Judy, 1988, p. 384). So far, the available evidence applies primarily to novices. It is not unlikely that the explanatory power of cross-domain skills may be marginalized with increasing expertise in a specific domain.

Nevertheless, these findings are inconsistent with the view that performance differences in argumentation can be accounted for by domain-specific knowledge and intelligence alone and that cross-domain strategic knowledge does not contribute to their explanation. Hence, this study provides evidence for the existence of cross-domain scientific reasoning and argumentation skills.

Conclusions

The question of whether cross-domain skills such as those of scientific reasoning and argumentation exist has been highly contested and answered differently across time. It appears that sometimes researchers tend to overemphasize the factor on which they focus in their own research as the main or even sole explanatory factor. Not as much in published work as in less formal venues, such as when acting as a reviewer for a journal or as a discussant at a conference, this view may be manifested as outright denial of the existence cross-of domain skills. Therefore, in this contribution we have thoroughly analyzed the methodological criteria that need to be imposed on research pertaining to the existence or non-existence of such cross-domain skills of scientific reasoning and argumentation, and we have identified three appropriate research paradigms for studying this question. We have presented results from these three paradigms as well as research of our own speaking in favour of the existence of cross-domain skills of scientific reasoning and argumentation. There is some indication that quasi-formal argumentative strategy knowledge may underlie these cross-domain skills.

Future research on cross-domain skills of scientific reasoning and argumentation should be based on a comprehensive theoretical framework of explanatory factors for performance such as the one sketched in this contribution, and exhibit the methodological sophistication that is necessary to rule out alternative explanatory factors. The operationalization of the general research question and the typology of research paradigms suggested in this contribution may be used as a starting point in this respect. Thus, it will be possible to focus more deeply on the interplay of cross-domain skills with domain-specific knowledge in explaining performance in scientific reasoning and argumentation tasks.

Epistemic Criteria: How Far Does General Knowledge Get You?

Clark A. Chinn, Ravit Golan Duncan, Ronald W. Rinehart, Rutgers University

The Problem

A core premise of much work in the learning sciences is that domain and topic knowledge are intimately involved in learning and reasoning processes. This poses a serious challenge to the assumption of many educational researchers that it is possible to teach students general skills or strategies that can be widely used across different topics and disciplines (e.g. Sadler & Donelley, 2006; von Aufschnaiter et al., 2008). For example, there continues to be broad interest in teaching skills (critical thinking, collaboration, control of variables) that are generally applicable. Similarly, science education research on promoting understanding of the nature of science (NOS) seems to posit that there is general knowledge about science that can be profitably taught. In contrast, proponents of the domain specificity of thinking argue that thinking differs so much from one domain to another that there is little point in attempting to teach anything general (e.g., Willingham, 2007).

Our goal is to work toward a theoretical analysis of ways in which general knowledge can and cannot be used across different domains or topics. We focus on epistemic practices given their importance to human knowledge development and their tight connection with the theme of this conference. We think that the debate on whether general epistemic practices exist, and can be productively taught, would profit from a more detailed theoretical analysis of what a person might gain through general knowledge of reasoning practices.

We draw on our experience in the PRACCIS project (Chinn et al., 2008; Duncan et al., 2011) working with middle school students engaged in extensive model-based inquiry instruction (several months to a full year in four separate implementations). One feature of PRACCIS is the development of epistemic criteria by classes. We have found that students readily develop class lists of epistemic criteria for evaluating models such as "good models fit all the good evidence" and "good models show all the steps in the process," and "good models are easy to understand." They can also develop criteria for good evidence such as "good evidence helps you decide which model is better" and "good evidence uses control groups." These criteria are used in conjunction with learning the content of a domain (e.g. genetics, natural selection). Here we consider some potential limitations of epistemic criteria in evaluating models and evidence.

The Limitations of General Knowledge of Epistemic Criteria

What are the limits of general knowledge of epistemic criteria? To answer this we first consider the situation in which a student tries to apply knowledge of such criteria to new domain with which they are fairly familiar. Two major difficulties that can arise in this situation: (1) *overgeneralization* and (2) *undergeneralization*. These problems are discussed in the literature on transfer (e.g., Schwartz et al, 2012). In the domain of epistemic criteria, we propose what we believe to be new solutions to these problems.

As an example of overgeneralization, a student who believes that good models show all the steps in the process might prefer a model of photosynthesis with 5 steps over one with 3 steps on the grounds that the 5-step model shows more steps – even though the two additional steps are not actually supported by any evidence. What this student fails to grasp is that some criteria take priority over other criteria. A prime solution to the problem of overgeneralization is to help students refine their general understanding of the *conditions* under which different criteria are applicable. In PRACCIS classes, teachers are encouraged to invite students to articulate conditions under which one might prefer a model with fewer steps over one with more steps. Consequently, students learn how to weigh competing criteria, and some of the conditions that govern which criteria take precedence in different situations. Thus, the problems of overgeneralization can be addressed in part by enabling students to develop an understanding of (still relatively general) conditions under which different criteria are to be applied.

Undergeneralization occurs when a student fails to apply a criterion when it is relevant. For example, a student may decide to adopt a diet based on a friend's anecdotal success while ignoring evidence about the health risks associated with this diet. Among several possible sources of undergeneralization, we would like to focus on one: Students may simply not believe that the epistemic criteria in question are valid. To facilitate students' acceptance of the criteria as valuable, we encourage teachers to hold meta-criteria discussions incorporating justifications for *why* different criteria should be adopted (or not adopted). For example, by discussing *why* one should prefer models that fit the evidence, students can come to appreciate the justifications for the use of fit-with-evidence criterion.

In short, the limitations of general knowledge of epistemic criteria can be addressed in part by helping students develop more nuanced (*conditionalized* and *justified*) but still relatively general epistemic criteria. But still, we argue below, there are limitations even to these more nuanced criteria.

The Limitations of Even Conditionalized and Justified Epistemic Criteria

Using the case of epistemic criteria, we have argued that general knowledge can be made more useful if it is conditionalized and justified. But, even if students learn more conditionalized and justified criteria, we argue that they will still be limited in their ability to apply these criteria to new domains. Our analysis identifies three specific limitations. First is the problem of *failure to identify referents***.** A student with a nuanced understanding of evidential criteria may nonetheless find it impossible to identify what the evidence is in an unfamiliar domain--that is, to pick out the referents of good evidence in the real world. For example, a student reading about whether vaccines cause autism may be committed to choosing the theory best supported by the good evidence, yet be simply unable to identify good evidence due to poor understanding of medical research design. Second, and a more serious difficulty, arises from *referent misidentification***.** A person applying evidentiary criteria would erroneously identify something as evidence when it is not. For example, a student studying global warming could fastidiously examine evidence of local weather conditions while failing to appreciate that this does not, by itself, count as evidence for long-term climate patterns. Third, and a particularly insidious problem, is *narrow knowledge*. Even if a student were competent in evaluating a piece of scientific evidence about the safety of vaccinations, the student lacks the experts' much more extensive knowledge of the boarder evidence base on the topic. Experts in scientific fields are aware of a vast array of evidence that laypeople are not aware of, and this gap cannot be redressed without becoming an expert oneself.

Unlike the under- and overgeneralization problems there is no solution to these three problems except deeper domain knowledge. Even a person with extensive general knowledge will suffer from *narrow knowledge* unless she herself gains true expertise in the field. As many have pointed out in recent years, ultimately in areas of non-expertise, one must trust experts (e.g., Bromme et al., 2009). All of this is not to say, however, that the general knowledge is not useful. A student who has a nuanced appreciation of evidentiary fit as an epistemic criterion will know at least two things that the student without this general knowledge will not know. First, the student with general knowledge of epistemic criteria will know a useful range of questions to ask experts in the field. The student could ask about types of evidence available as well as sample size and control groups. Further, the person who has learned epistemic criteria will have command of some of the discourse practices of the expert community and will have a greater capacity to seek out information.

Evidence against Using Domain-General Examples to Teach a Domain-General Concept/Skill

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The long term goal of instruction is to have students acquire knowledge and skills that are widely applicable, rather than tied to the specific context in which they were acquired. However, the question about whether the initial learning materials and contexts should be domain-general or domain-specific, remains controversial. A substantial body of research has found that embedding domain-specific information in instructional examples helps learners understand these examples (e.g., Goldstone & Son, 2005; Goldstone & Sakamoto, 2003; Koedinger & Nathan, 2004; Kaminski, Sloutsky, & Heckler, 2006; Witzel, Mercer, & Miller, 2003). However, some research suggests that using domain-specific materials inhibits transfer to novel contexts (Kaminski et al., 2006; 2008; 2013; Bassok & Holyoak, 1989; Goldstone & Sakamoto, 2003). Consistent with these findings, which suggest that domain-specific information supports initial learning and abstracted representations better support transfer to new domains, Goldstone and Son (2005) found that transfer performance among college undergraduates was greatest when the domain-specific information was "faded" during the training task (or present initially in the training session and "removed" later). We describe a study that investigated the effect of fading domain-specific information in instructional examples on transfer outcomes.

Method

The domain-general concept/skill taught was simple experimental design. In the sections of instruction discussing domain-specific examples of experimental set-ups, specific variables and values were used in examples and in instructional explanations (e.g., "to determine whether the slope of the ramp affects how far balls roll, one should make one ramp steep and the other not steep and make the surface, starting position, and type of ball the same for the two ramps"). In the sections of instruction discussing domain-general examples, experimental variables and their respective values were described generically as "Variable A/B/C" and their levels only given as "the same" or "different" across conditions. Instructional explanations were more abstract (e.g., "to determine whether Variable X affects the result, one should make Variable X different across conditions and all other variables the same across conditions").

6th- and 7th-grade students at a suburban middle school worked individually on computers learning how to design unconfounded experiments in one of three conditions. In all conditions, students evaluated a series of three experiments. After each evaluation, students received feedback on their evaluations followed by explanations for why the experiments were or were not "good experiments." All instructional experiments were represented in tabular/text form (i.e., no pictures of the set-ups were present). In the "all-concrete" condition, students evaluated three experiments using ramps; each experiment included specific variables (e.g., slope) and corresponding values (e.g., steep/not steep). In the "concrete fading" condition, students first evaluated a concretely-represented ramps experiment (as in the first condition), then an intermediately concrete experiment (with specific ramps variables but unspecified values represented only as "the same" or "different" across conditions). In the final, "abstract fading" condition, the experimental presentation order was reversed from the concrete-fading condition. The next day, all students completed a test assessing their ability to transfer their knowledge to domains other than ramps.

Results

Results suggest that the benefits of incorporating this additional information (i.e., the specific experimental variables and their values) throughout instruction were greater for younger and lower-ability students: The transfer performance of younger students (6th-graders) and lower-ability 7th-graders was generally best in the all-concrete condition. However, higher-ability 7th-graders performed equally in the all-concrete and concrete-fading conditions and better than students in the abstract-fading condition. Across the board, students performed poorly in the abstract-fading condition, suggesting that supporting domain-specific information is in general critical in the early stages of learning. A post-hoc analysis suggested that the additional concrete features supported students' ability to identify experimental confounds, or variables that—because they were contrasted across conditions – may have affected the outcome.

Discussion

Our results are counter to Goldstone and Son's (2005) finding that fading domain-specific information during training led to better performance of college undergraduates on novel transfer problems. Instead, we found that the transfer of domain-general experimental design skills was best when domain-specific examples were included throughout instruction. However, among the older students, the concrete-fading and all-concrete conditions performed similarly on the transfer task. One possible reason for these differences is that the continued exposure to domain-specific examples was necessary to support younger and lower-ability students' understanding of the impact of confounded variables, a concept that was not as effectively conveyed in the abstracted form of the instruction. These results suggest the possibility that—at least when additional domain-specific information directly supports learners' understanding of the instructional topic—instructional materials and contexts that are *not* domain general may be most effective for teaching younger and lower-ability students a domain-general concept/skill. However, because this study included only minimal additional domain-specific information, further research is necessary to determine the optimal amount of information to support transfer as well as how it interacts with student characteristics such as prior knowledge and general ability.

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