Scientific reasoning as domain specific or general knowledge. A discussion

André Tricot

CLLE Laboratory and Faculty of Education, CNRS, University of Toulouse, France

Correspondence: André Tricot, CLLE, University of Toulouse, Maison de la recherche, 5 allée Antonio Machado, 31 058 Toulouse, France. Email: Andre.Tricot@univ-tlse2.fr

In F. Fisher, C. Chinn, K. Engelmann & J. Osborne (Eds.), Scientific reasoning and argumentation: The roles of domain-specific and domain-general knowledge. (pp. 271-277). New York: Routledge.

Scientific reasoning as domain specific or general knowledge: a discussion

Let's consider knowledge as a trace of one individual's past that makes them able to perform task(s). Humans share the ability to perform tasks and to develop knowledge with many other animal species and with humans from other times. For example, during the Upper Paleolithic (250,000 to 40,000 or 30,000 years ago), there is evidence for "rapid technological changes, emergence of self-awareness and group identity, increased social diversification, formation of long-distance alliances, the ability to symbolically record information" (Bar-Yosef, 2002) far before the invention of science. An example of the relationship between task and knowledge is the following. If you know the Pythagoras theorem, then you are supposed to be able to perform the task: "How long is the hypotenuse of a right-angled triangle, when the two sides of the right angle are 3 km and 7 km." If you do not know the Pythagoras theorem, then performing this task is almost impossible. Performing this task implies this knowledge. If you know the face of the singer James Brown, then you are supposed to be able to recognize a picture of James Brown's face. This last skill is typically general knowledge: You can use your face recognition skills to recognize any face in the world, including several non-human primates (with different level of performances, but you can do it; see *e.g.* Pascalis, de Haan, & Nelson, 2002; Rehnman & Herlitz, 2006). From Aristotle to Piaget, many theories of human knowledge have assumed that scientific reasoning is the kind of knowledge that humans can use in any task, when this knowledge is needed and relevant. Typical general scientific knowledge was, for Aristotle and Piaget, formal logic.

Unfortunately for human beings, it is not that simple. For example, a large amount of cognitive psychology literature is devoted to the study of cognitive biases—

i.e., the fact that individuals can know something (*e.g.*, a particular form of reasoning) and be unable to use it to perform several tasks that nevertheless involve this knowledge (Evans, 2003). In other words, you can be unable to solve problems involving this Pythagoras theorem even when you know it. Researchers in this domain tries to answer questions like: Why do individuals sometimes think to use this knowledge to perform this task, and sometimes not? Why do they use other types of knowledge? I would like to discuss another way to address this issue: When an individual knows scientific reasoning, is there a restriction to the set of tasks that they are able to perform with? I will discuss this aspect with the authors of the three papers of this section "Exploring the role of domain-general knowledge."

Knowledge and tasks and a way to define "domain"

Most of the discussions on domain specific vs. general knowledge have to deal with the definition of the word "domain." Hetmanek et al. (this volume) consider "domain" as an epistemological construct. For example, biology is a scientific domain. Physics is another one. Their proposal about scientific reasoning and argumentation as a cross-domain conceptualization, is—following this view of "domain"—very interesting and promising. If a scientific knowledge is relevant in several different domains, then it can be very interesting to teach it as a cross-domain knowledge. Based on Fischer et al. (2014), the authors identify eight distinct epistemic activities that play a role in the scientific process of knowledge generation in disciplines as different as mathematics, biology, medicine, psychology, educational science, computer science, and social work. Hetmanek et al. also write that it is important not to ignore differences between domains: "Evidence generation, to give an example, follows very different standards in mathematics (mathematical proof generation) compared to experimental psychology (generation of evidence using experimental manipulations).” I’m not able to imagine reasons to teach science in another way than a cross-domain knowledge approach to students involved in several domains. As the authors argue, the cross-domain approach is a way to circumvent the domain specific vs. general knowledge debate. But I would like, after Tricot and Sweller (2014), to propose a very different way to define “domain,” let’s say in a psychological way.

Tricot and Sweller (2014, p. 266) defined “domain-specific knowledge as memorised information that can lead to action that permits specified task completion over indefinite periods of time. For example, there are many different problems that can be solved by using Pythagoras’ theorem. To use the theorem to solve problems, problem solvers must not only learn the theorem, they also must learn to recognise the various problems to which the theorem can be applied and the manner in which it should be applied in each case [underlined here]. We define this set of problems as a “domain” and Pythagoras’ theorem along with the manner in which it can be used is a constituent of the domain-specific knowledge required to solve this set of problems. That knowledge, consisting of large numbers of problem states and the moves associated with those states, is stored in long-term memory.”

Following this definition of domain-specific knowledge, if there is a very new problem, that one individual never solved with Pythagoras’ theorem, then it is probable that this individual will not use Pythagoras’ theorem to solve this problem. For example: “Consider two points 200 meters apart from each other. A 200.04 meters long rope can be fixed between the two points, so it is too long by 4 cm. The rope is raised in the middle of the two points, 100 meters from each, until it is taut. How far is it raised? About 2 cm? About 20 cm? About 2 m?” Most people (even several maths students in Toulouse School of Education, France) fail to solve this problem. However, it is possible to solve this problem by using Pythagoras' theorem. Following our approach, if someone "knows" the theorem but does not think to use it to solve this rope problem, it just means that their knowledge about the theorem is incomplete: It is not matched to this task.

Let us consider Pythagoras' theorem again. An individual may know that you can use it in trigonometry to demonstrate that $\sin^2\alpha + \cos^2\alpha = 1$. If the individual understands this demonstration, then they can improve their knowledge about Pythagoras' theorem and about trigonometry. We define $\sin^2\alpha + \cos^2\alpha = 1$ as an added representation level of Pythagoras' theorem.

Summary: Domain-specific knowledge is a limited set of tasks associated with particular knowledge. The fact that this knowledge is relevant to perform a task in not enough to use it.

According to Tricot and Sweller (2014, p. 266), "Domain-general skills, by definition, can be used to solve any problem in any area. For example, learning to solve problems by thinking of similar problems with known solutions is an example of domain-general knowledge that can be applied to all problems. Such domain-general knowledge also is stored in long-term memory although (…) it belongs to a different knowledge category that for biological evolutionary reasons may be learnable but unteachable because it already will have been acquired automatically without instruction, outside of an educational context. (…) while people cannot learn an already learned, domain-general skill, they can learn to apply the skill in a new domain, thus providing an example of the acquisition of domain-specific rather than domain-general knowledge."

Summary: Domain-general knowledge is a set of tasks associated with a knowledge, as far as this knowledge is relevant. When this knowledge is relevant to perform a task, it is used.

Following this approach, the size of the set of tasks is not limited for domain-specific knowledge nor unlimited for domain-general knowledge. Size does not matter. For example, reading is domain-specific knowledge (you can only read words in languages and alphabet you know) but the set of words you can read is almost unlimited. When Tricot and Sweller (2014) wrote that instruction should be focused on domain-specific knowledge, they referred to this definition of domain. That's why I don't think that this point of view is opposed to Hetmanek et al.'s point of view, based on a very different definition of "domain." That is why I do not "conclude that teaching the [Hetmanek et al.'s] conceptual framework of scientific reasoning and argumentation is useless."

Learning and instruction

When Tricot and Sweller (2014) wrote that instruction should not be focused on domain-general knowledge, it was just a way to say: It is not necessary to teach it because domain-general knowledge is already known. For example, problem solving is not teachable just in the sense that problem solving is already known. Sodian's chapter provides very strong argument supporting this point of view. She quotes Gopnik (2012, p. 1623): "Very young children's learning and thinking skills are strikingly similar to much learning and thinking in science: Preschoolers test hypotheses against data and make causal inferences, they learn from statistics and informal experimentation...." But she also writes: "It is not clear whether and to what extent young children are similar to scientists in terms of intentionally guided knowledge seeking processes." Sodian argues very convincingly that children reason, and this reasoning develops since early years, from weak to strong scientific ways of reasoning. Part of this development is linked to knowledge learnt at school. Hypothesis testing is "primary knowledge" (Geary, 2008), used by humans for several tens of thousands years and by other animal species. Testing scientific hypotheses is "secondary knowledge," discovered by humanity probably fewer than 3,000 years ago (Van de Schoot, Hoijtink, & Jan-Willem, 2011); it is learnt at school, still developing at university and during adulthood for scientific professionals. Adults still exhibit confirmation bias (Nickerson, 1998), which is an evidence that testing scientific is not general knowledge, not used by everyone, and even not used every time it is relevant.

It is obvious that there are other conceptions of learning by instruction than Tricot and Sweller's one. For example, learning by instruction is also extending the validity domain of particular knowledge, *i.e.* extending the set of tasks one individual can perform with this knowledge. I would like now to examine the link between this other conception of learning by instruction and domain-specific knowledge in scientific reasoning.

Scientific reasoning

As Kind and Osborne (2017) argued, scientific reasoning has been developed in human societies through history. Scientific reasoning is a cultural activity, *i.e*. the kind of activity that "individuals socially learn to the degree that different populations of a species develop different ways of doing things" (Tomasello, 2009). That is probably one of the reason why "there are no general, universal rules of reasoning," nor one Science but several Sciences (Kind & Osborne, 2017). These authors described three forms of scientific knowledge (Ontological, Procedural, Epistemic) and six styles of scientific reasoning (Mathematical Deduction, Experimental Evaluation, Hypothetical Modeling, Categorization and Classification, Probabilistic Reasoning, Historical-Based Evolutionary Reasoning). They cross these two dimensions and obtain a 3x6 table. For example, the Procedural x Experimental Evaluation cell contains: Identification of variables, Control of variables, Procedures for minimizing error. The Epistemic x Epistemic contains: Hypothesis, Experimental tests, Arguments based on controls/double blind testing. Etc. This approach is highly convincing: scientific knowledge is a set of domain-specific knowledge. "Double blind testing" for example is highly specific: There are a lot of scientific problems that can't be solved with "Double blind testing."

But I would like to examine another argument about the specificity of scientific knowledge: When an individual knows a scientific procedure, are they able to use it for any kind of task (ability to transfer)? Or is that limited to the task they usually perform with this knowledge (no transfer)? In other words, if "double blind testing" is learnt to perform one task, is that enough to use it for every scientific problem that needs it to be solved? Following Tricot and Sweller's proposal, if we answer yes to this question, then we can consider "double blind testing" as domain-general knowledge. If we answer no to this question, then we can consider "double blind testing" as domain-specific knowledge. Learning to use this knowledge to perform new tasks is the kind of learning that we can call "extending the domain of knowledge validity".

Learning by instruction can be seen as developing much domain-specific knowledge and by extending the domain of knowledge validity. Developing expertise and intelligence can be seen in exactly the same way. We do not need the concept of domain-general knowledge to support the fact that some individuals perform very well in one or several academic or professional domains (Bilalić, McLeod & Gobet, 2007). Domain-specific knowledge is enough to explain acquired expertise and intelligence.

As Kienhues, Thomm and Bromme (this volume) argue, there are many empirical findings that provide evidence about the ability of individuals to sometimes transfer their knowledge, sometimes not. My evolutionary argument is the following: From a cognitive processing point of view, most of the domain-specific scientific knowledge is also domain-general folk knowledge (*e.g.* hypothesis testing). From an historical, evolutionary and cultural point of view, they are absolutely different. There are many situations where general / folk knowledge and specific / scientific knowledge used in reasoning or argumentation lead to the same conclusion: for example, "All pizzas are fat; And the five cheese is a pizza; Then the five cheese is fat" is a kind of folk knowledge that humans use very easily and a valid syllogism (Lespiau, Bonnefon & Tricot, 2017). It does not mean that the two forms of knowledge are the same (De Neys & Bonnefon, 2013). Familiarity with the situation and coherence with intuition are two examples of factors that increase the probability to use of general / folk knowledge. It is also possible to increase the transition between general / folk knowledge and specific / scientific knowledge (Markovits & Lortie-Forgues, 2011; Lespiau, Bonnefon & Tricot, 2017).

Summary

This discussion was about the three chapters of the section on exploring the role of domain-general knowledge in scientific reasoning. These three important contributions open the domain specific *vs*. general knowledge debate to cross-domain knowledge, to the development of scientific knowledge, and to layers of scientific knowledge. These chapters consider "domain" in a way that I wanted to discuss. Here is a summary of my proposal:

Let's consider a set of tasks Tx {Tx1; Tx2; Tx3… Txn} and knowledge Kx

And that Tx -> Kx (*i.e.* performing Tx implies mastering Kx).

Domain Dx is the set of tasks Tx that can be performed with knowledge Kx.

e.g., Kx is the Pythagoras theorem and Tx the set of problems that implies mastering the Pythagoras theorem.

Domain-specific knowledge DsKx = {(Tx1;Kx), (Tx2;Kx) … (Txn;Kx)}.

e.g., Pythagoras theorem's domain-specific knowledge is a set of problems, each problem being associated with the theorem.

With domain-specific knowledge, couples (Tx1;Kx), (Tx2;Kx)… have to be learnt.

e.g., Problems associated with the theorem have to be learnt. Mastering the Pythagoras theorem is not enough to solve every problem (like the rope problem presented above) implying this theorem.

Let's now consider that Kx is usable for any Tx where Kx is relevant.

Then, domain-general knowledge, DgKx = {Tx1, Tx2, Tx3… Txn; Kx}.

e.g., Domain-general knowledge like face recognition skills are usable to recognise any face. It is not needed to learn using face recognition skills to recognise a new face.

In this approach, the main difference between DsK and DgK, is that DsK is a set of couples (Tx1;Kx) whereas DgK is a set of Tx associated with Kx. With DgK, Kx can be used whenever it is relevant.

The size of the set of tasks is not limited for DsK nor unlimited for DgK.

My claim is that scientific knowledge as a very recent type of cultural knowledge is domain-specific knowledge*, i.e.* not a limited knowledge, but where extending the domain of knowledge validity is the main aim of learning by instruction, based on teaching an increasing number of tasks involving this knowledge.

References

Bar-Yosef, O. (2002). The upper paleolithic revolution. Annual Review of Anthropology, 31(1), 363-393.

Bilalić, M., McLeod, P., & Gobet, F. (2007). Does chess need intelligence? A study with young chess players. Intelligence, 35(5), 457-470.

De Neys, W., & Bonnefon, J. F. (2013). The ‘whys’ and ‘whens’ of individual differences in thinking biases. Trends in Cognitive Sciences, 17(4), 172-178.

Evans, J. S. B. (2003). In two minds: dual-process accounts of reasoning. Trends in cognitive sciences, 7(10), 454-459.

Fischer, F., Kollar, I., Ufer, S., Sodian, B., Hussmann, H., Pekrun, R., … Eberle, J. (2014). Scientific reasoning and argumentation: Advancing an interdisciplinary research agenda in education. Frontline Learning Research, 4, 28–45.

Geary, D. C. (2008). An evolutionarily informed education science. Educational Psychologist, 43(4), 179-195.

Gopnik, A. (2012). Scientific thinking in young children: Theoretical advances, empirical research, and policy implications. Science, 337(6102), 1623-1627.

Kind, P., & Osborne, J. (2017). Styles of Scientific Reasoning: A Cultural Rationale for Science Education? Science Education, 101(1), 8-31.

Lespiau, F., Bonnefon, J.-F., & Tricot, A. (2017). Primary vs. secondary knowledge as a way to present logical problem solving. 10th International Cognitive Load Theory Conference, Wollongong, 20-22 November.

Markovits, H., & Lortie-Forgues, H. (2011). Conditional reasoning with false premises facilitates the transition between familiar and abstract reasoning. Child Development, 82(2), 646-660.

Nickerson, R. S. (1998). Confirmation bias: A ubiquitous phenomenon in many guises. Review of General Psychology, 2(2), 175.

Pascalis, O., de Haan, M., & Nelson, C. A. (2002). Is face processing species-specific during the first year of life? Science, 296(5571), 1321-1323.

Rehnman, J., & Herlitz, A. (2006). Higher face recognition ability in girls: Magnified by own-sex and own-ethnicity bias. Memory, 14(3), 289-296.

Tomasello, M. (2009). Why we cooperate. Cambridge, MA: MIT press.

Tricot, A., & Sweller, J. (2014). Domain-specific knowledge and why teaching generic skills does not work. Educational Psychology Review, 26(2), 265–283. doi.org/10.1007/s10648-013-9243-1

Van de Schoot, R., Hoijtink, H., & Jan-Willem, R. (2011). Moving beyond traditional null hypothesis testing: evaluating expectations directly. Frontiers in Psychology, 2, Article 24