



Primary vs. secondary knowledge contents in reasoning: Motivated and efficient vs. overburdened

Florence Lespiau, André Tricot

► To cite this version:

Florence Lespiau, André Tricot. Primary vs. secondary knowledge contents in reasoning: Motivated and efficient vs. overburdened. *Acta Psychologica*, 2022, 227, pp.103610. 10.1016/j.actpsy.2022.103610 . hal-03685668

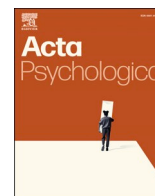
HAL Id: hal-03685668

<https://hal.science/hal-03685668>

Submitted on 10 Apr 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Primary vs. secondary knowledge contents in reasoning: Motivated and efficient vs. overburdened

Florence Lespiau^{a,*}, André Tricot^b

^a Univ. Nîmes, EA7352 CHROME, Rue du Dr G. Salan, 30021 Nîmes Cedex 1, France

^b EA 4556 EPSYLON Univ. Paul Valéry Montpellier 3, Univ. Montpellier, EPSYLON EA 4556, F34000 Montpellier, France

ARTICLE INFO

Keywords:

Dual-process
Evolutionary psychology
Presentation order
Cognitive load
Engagement

ABSTRACT

Primary knowledge is the knowledge for which our cognitive architecture has evolved so that we acquire it quickly and effortlessly. We are intrinsically motivated to process it. Secondary knowledge is the knowledge for which our cognitive architecture has not had enough time to evolve: it requires time, cognitive resources and is hardly motivating. This study proposed to test these evolutionary characteristics using the experimental paradigm of logical reasoning. We conducted five experiments ($n = 720$) varying (i) the content of syllogisms (primary or secondary knowledge), (ii) the presentation order of the knowledge types, (iii) the added extrinsic cognitive load, and (iv) the type of syllogism. Results showed that primary knowledge increased performance, emotional and cognitive investment and decreased perceived cognitive load. Second, presenting primary knowledge first would encourage participants to be motivated throughout the task, while presenting secondary knowledge first would undermine their motivation. Third, secondary knowledge seemed to lead to a feeling of conflict that consumed cognitive resources. All together, these results suggested that primary knowledge should be taken into account and not left aside because it is something “already learned”.

1. Introduction

No one knows how to teach to speak an oral mother tongue, but we know how to teach a second language or teach to write. Indeed, on one hand there is knowledge so quickly acquired that it is not even possible to explain how to do so, and, on the other hand, there is knowledge that is hard to acquire. The difference between these two knowledge types is not a question of complexity: learning to speak a mother tongue is at least as complex as learning to speak a second language, if not more complex, since it implies being able to initially differentiate phonemes and synchronize phonatory muscles for example. According to the evolutionary approach to knowledge (Geary & Berch, 2016), the difference would lie in their adaptive utility and acquisition time during evolution.

1.1. About the knowledge we acquire and the knowledge we learn

A recent theory in evolutionary psychology (Geary, 2007, 2008, 2012; Geary & Berch, 2015, 2016) proposed to differentiate between two types of knowledge in relation to their acquisition time during evolution and their adaptive utility. Human universal primary abilities

(e.g. language, face processing, spatial navigation) are assumed to have an inherent cognitive architecture that focuses attention on relevant aspects of the environment and a motivational bias that led children to engage in activities (e.g. social play) that flesh out these abilities during development and adapt them to local conditions (Geary, 1995; Gelman, 1990). According to this theory, with sufficient time, our mechanisms have evolved to facilitate the acquisition of adaptive knowledge, giving them special characteristics. For example, being able to communicate as soon as possible with direct partners was undoubtedly a skill that was favored by natural selection. Thus, human cognitive mechanisms had evolved to facilitate the acquisition of a particular mother tongue and more generally adaptive knowledge dependent on direct socio-environmental conditions (Geary, 2008; Geary & Berch, 2016). Conversely, knowledge that emerged more recently in the timescale of evolution (e.g. reading, writing, mathematics), do not benefit from early advantages that facilitate its learning and thus basic skills need to be explicitly learned (e.g. teaching of phonetic decoding during early reading). Secondary abilities are not universal; they tend to emerge only in contexts, especially school, that are explicitly designed to foster their acquisition. Learning in these evolutionarily-novel domains is predicted to demand working memory resources, and thus be effortful. Moreover,

* Corresponding author.

E-mail address: florence.lespiau@unimes.fr (F. Lespiau).

<https://doi.org/10.1016/j.actpsy.2022.103610>

Received 22 August 2021; Received in revised form 8 April 2022; Accepted 4 May 2022

Available online 16 May 2022

0001-6918/© 2023 Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

there is no inherent, universal motivation to learn things such as phonetic decoding and thus most children would need some type of extrinsic structure to facilitate their learning (Castles, Rastle, & Nation, 2018).

Universal primary abilities lead humans to the possibility to learn adaptive primary knowledge, that may concern (Geary, 2007, 2008, 2012; Geary & Berch, 2015, 2016) folk psychology (e.g., self-awareness, face recognition, facial expressions, language, group dynamics, theory of mind), folk biology (e.g., fauna, flora, food) and folk physics (e.g., navigation, sense of time, tool use). The material developed for the present study involved processing information and making judgments about food and fauna (folk biology). Humans are particularly effective and intrinsically motivated to acquire and process this type of knowledge because it is directly relevant to individual adaptation and survival (Geary, 2008; Geary & Berch, 2016; Geary & Bjorklund, 2000). The primary knowledge is modular (e.g., modularity of the feeling of number, Mandelbaum, 2013; module for detecting cheaters, Cosmides, Barrett, & Tooby, 2010; module of theory of mind, Scholl & Leslie, 1999; module of face recognition, Kanwisher, McDermott, & Chun, 1997) mainly because this knowledge was acquired at different times at the level of evolution (Tricot & Sweller, 2014). For example, it is easy to imagine that one would have learned to recognize faces before learning to speak.

Secondary knowledge is defined as opposed to primary knowledge: it requires time, effort (cognitive resources) and a great deal of motivation. It is difficult and time-consuming to acquire because our brain did not have enough time to adapt to it (e.g., all the so-called “academic” knowledge; Sweller, 2015). When we are faced with secondary knowledge, we have neither the motivation nor the ability (genetically inspired) to assimilate it automatically. In addition, knowledge that are not part of our direct environment are considered secondary knowledge (Roussel, Joulia, Tricot, & Sweller, 2017) while primary knowledge is specifically adapted to the local environment (Geary, 2007). Primary knowledge is considered to be acquired under specific conditions but in the long term generalizable (usable in any field of application and situation) while secondary knowledge is more specific, defined by its necessity to perform a task (Tricot & Sweller, 2014). The difference between primary and secondary knowledge would therefore not be related to a difference in concreteness or complexity but rather to a difference in the time of evolution.

The evolutionary history is not precise, so it is impossible to say that a particular skill belongs strictly to the primary or secondary domains (Tricot & Sweller, 2014). The consensus for determining a primary knowledge or skill is simple: primary knowledge does not need to be explained to be understood (Paas & Sweller, 2012). The fuzziness of this distinction is accentuated by the fact that secondary knowledge is built from primary knowledge. To use our first example, individuals born and living in France acquire “a” French language as a primary knowledge quickly and effortlessly. It depends on their immediate environment. At school, they learn “the” French language (Roussel et al., 2017) and other forms of oral communication such as lectures which, although built on primary knowledge, requires efforts as secondary knowledge (Sweller, Ayres, & Kalyuga, 2011). How primary systems are used to build secondary knowledge is not fully understood. Evidence that this occurs may be found with the substantive overlap in the brain and cognitive systems that supports language (primary) and reading/writing (secondary) (Price, 1998). Another example: before we could count, we have an approximate number system (ANS) that would be the basis for an approximate numerical system and then symbolic cardinal values (Chu, vanMarle, & Geary, 2015). The idea is then to use the characteristics of primary knowledge to promote the processing of secondary knowledge. This was being tested in a series of empirical studies (Glenberg, Goldberg, & Zhu, 2011; Kirschner, Paas, & Kirschner, 2011; Mazzocco, Feigenson, & Halberda, 2011; Paas & Ayres, 2014; Paas & Sweller, 2012; Ping & Goldin-Meadow, 2010; Van Gog, Paas, Marcus, Ayres, & Sweller, 2009; Youssef, Ayres, & Sweller, 2012): primary knowledge facilitates the acquisition of secondary knowledge, particularly through the use of

primary mechanisms that increase working memory capacity and reduced the impact of cognitive load promoting learning. In solving conditional rules, primary knowledge contents with unfamiliar words increased performance, emotional and cognitive engagement, confidence in responses and decreased perceived cognitive load (Lespiau & Tricot, 2018). The use of primary knowledge in a learning task could also make it possible to invest learners more efficiently (Lespiau & Tricot, 2019).

Until recently, the limited capacity of working memory was thought to apply to the acquisition of all kinds of information (Paas & Sweller, 2012). However, our cognitive system has evolved to easily acquire primary knowledge, its acquisition requires very little working memory resources regardless of its complexity (e.g., speaking is a complex activity combining motor skills, sounds, gesture, etc.). Conversely, when secondary knowledge is at stake, individuals do not have the processing facilitation skills related to cognitive system mutation, nor the motivation to automatically assimilate information. The cognitive load theory then applies only to secondary knowledge (Sweller, 2008).

Evolutionary psychology thus enables conceiving a new differentiation of knowledge based on its acquisition time in relation to evolution and its adaptive utility. Our cognitive structures would have evolved to support the acquisition of primary knowledge, assigning specific characteristics to it (e.g., intrinsically motivating knowledge, acquired quickly and effortlessly), unlike secondary knowledge which require cognitive resources and motivation to be processed. However, this theory is difficult to test because, if the two types of knowledge are different, they are not comparable. In this paper, we therefore propose to test the evolutionary theory in the field of reasoning, because it allows a direct comparison between two contents of the same logical problem.

1.2. About the two types of mechanisms involved in reasoning

According to dual-process approach (Evans, 2003, 2016; Evans & Frankish, 2009; see De Neys, 2021 for a recent discussion), information may be processed through two different types of mechanisms. Types 1 are fast, automatic processes that are not limited by working memory capacity. They are systematically implemented and are responsible for individuals' first response to a problem of formal logic for example. Types 2 are slower, implemented only when a conflict is detected between Type 1 and Type 2 response (even unconscious, De Neys, 2012; De Neys, Cromheeke, & Osman, 2011; De Neys & Glumicic, 2008; De Neys, Moyens, & Vansteenwegen, 2010; De Neys, Vartanian, & Goel, 2008; Kahneman & Frederick, 2005), subject to first response inhibition (De Neys & Franssens, 2009) and sufficient resources available in working memory to generate Type 2 response (De Neys & Bonnefon, 2013). Considering these syllogisms in which the logical validity of the conclusion was to be judged:

*All mammals can walk,
Cats are mammals,
Therefore cats can walk. (1)*
*All cakes can be eaten,
Chocolate cookies can be eaten,
Therefore chocolate cookies are cakes. (2)*

In syllogism (1), the conclusion is valid (logically) and believable (empirically). These two validities being similar (non-conflict problem), it leads to the same correct answer “valid”. However, in syllogism (2), the conclusion is not valid (logically) but believable (empirically). These two validities being dissimilar (conflict problem), it leads to a conflict between the answer of Type 1 (based on belief heuristics, incorrect response “valid”, leading to a belief bias) and Type 2 (based on the logical norm, correct response “non-valid”). Compared to non-conflict problems, conflict problems, in addition to a poorer performance (De Neys, 2006), led to longer response times (De Neys & Glumicic, 2008; Handley & Trippas, 2015) and individuals appeared to have less confidence in their responses (De Neys & Feremans, 2013; Johnson, Tubau, & De Neys, 2016).

The dual-process theoretical framework investigated what mechanisms were involved in solving problems that may induce belief bias. Numerous studies had shown that the addition of a cognitive load in working memory with a Dot Memory Task (Bethell-Fox & Shepard, 1988; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001) increased the number of heuristic responses in formal logic problems (De Neys, 2006; Trémolière, Gagnon, & Blanchette, 2017): cognitive resources in working memory were used to perform the interfering task (high cognitive load modality) and were less available for conscious reasoning. Cognitive overload could interfere with correct reasoning in conflict problems (problem valid but unbelievable or invalid and believable) but not in non-conflict problems, when beliefs led individuals to the correct answer.

Type 1 processing is considered universal, supporting survival, whereas Type 2 processing is more personal utility directed (Stanovich and West, 2000). Moreover, our reasoning in everyday life is to be effective in a limited time with incomplete and doubtful information (heuristics) (Morsanyi & Handley, 2008). These strategies are far different from those that must be used in logical problems, requiring more conscious thought, efforts and time (analytical). The classical normative logic is secondary knowledge because we did not evolve to be logical (Stanovich, West, & Toplak, 2011), we learn to be effective most of the time (Geary & Bjorklund, 2000). Wason's (1966) selection task is an example of this difference. When this task was presented abstractly, 10% of participants passed the task (Fiddick, Cosmides, & Tooby, 2000) whereas when presented in a context of social relation (beverage), 75% passed the task (Griggs & Cox, 1982). This ease of treatment is not related to the concrete, realistic or familiar character of the content, but to a deontic aspect of cheaters detection (Cosmides et al., 2010; Fiddick et al., 2000; Valiña & Martín, 2016). This deontic aspect does not even need to actually exist or be concrete (Cosmides & Tooby, 2004; Dominowski, 1995; Gigerenzer & Hug, 1992) and is acquired early (children aged 2–3; Beller, 2010). Taking into account the evolutionary approach of knowledge, deontic rules would be a primary knowledge and thus would be easily and efficiently processed whereas the abstract task would be a secondary knowledge (pure logic rule). Primary knowledge would make it easier to solve the problem since it does not require specific cognitive resources, whereas secondary knowledge would load the working memory. Type 1 mechanisms share several characteristics and functioning with primary knowledge, like Type 2 or secondary knowledge; but cognitive mechanisms and knowledge types do not overlap (e.g. secondary knowledge can be fully automated to become Type 1 knowledge through extensive practice and expertise).

Interest in reasoning is threefold in the present study. First, contextually, formal logic skills are sought in our modern societies because they convey the myth of being able to reason about all problems in an abstract way (Binkley et al., 2012; Cosmides & Tooby, 2004; Markovits & Lortie-Forgues, 2011). However, humans have evolved to provide quick and effective responses that do not always meet the expectations of formal logic (Stanovich & West, 2000). In fact, the rules of logic used in the present study can be assimilated to secondary knowledge. Second, problems of logic, especially syllogisms that may induce belief bias, allow to explore the mechanisms underlying their resolution activity and thus to make the link between the well-documented dual-process approach and the evolutionary theory of knowledge. Third, logical problems have the methodological possibility of easily getting various contents such as primary and secondary knowledge contents.

2. Present study

This study sought to test the evolutionary approach of knowledge through paradigms used by research on reasoning. The approach was similar to that taken by Fiddick et al. (2000), but expanded on these with the explicit distinction between primary and secondary domains and with inclusion of motivation, affective, and working memory issues. To this end, we conducted five experiments. Each participant was faced

with syllogisms involving primary knowledge content (food, animal characteristics) or secondary knowledge content (grammatical rules, mathematics) with known or unknown words. If we succinctly noted “primary knowledge” or “secondary knowledge” in the following parts of the article, we referred to information about topics in primary or secondary knowledge domains. By definition (Geary & Berch, 2016), primary knowledge requires less cognitive resources thus is processed more quickly and easily compared with secondary knowledge. This ease of processing could give a false impression of familiarity or concreteness, particularly when using known words. However, it appears that the young Occidentals who compose our samples spend much more of their daily time processing secondary knowledge than primary knowledge (Beck & Richard, 2010; Génolini, Ehlinger, Escalon, & Godeau, 2016; Guichemerre, 2011; Léon, du Roscoät, Ehlinger, & Godeau, 2016; Pacoricona Alfaro, Ehlinger, Sentenac, & Godeau, 2016): our participants were high school students or university students who spend more time learning and applying secondary knowledge such as grammatical rules or mathematics than dealing with how to process food so that it can be or not eaten. We measured performance, but also emotional and cognitive investment, confidence in given responses and perceived cognitive load. The first objective was to highlight the characteristics of primary and secondary knowledge.

Hypothesis 1. In particular, the effortless and motivating aspect of primary knowledge should encourage performance and engagement in a task of reasoning (involving normative rules as secondary knowledge) compared to secondary knowledge.

In addition, formal logic rules, like all secondary knowledge, require time, cognitive resources and motivation. Even the most motivated individuals often feel discouraged by the task and abandon their learning of logical rules. When looking at the field of learning by instruction, the main issue is to foster motivation, pleasure in learning and engagement in learning tasks (Braver et al., 2014; Cosnefroy, Nurra, & Dessus, 2016). Our idea was therefore to use the characteristics of primary knowledge as a basis for motivating participants when facing secondary knowledge.

Hypothesis 2. The order of presentation of knowledge types, such as primary knowledge being presented first, motivated participants to proceed with the task.

Finally, we manipulated the added extrinsic cognitive load of the tasks (using reversed words or a Dot Memory Task) and the syllogisms type (conflict or non-conflict) to investigate the mechanisms involved in solving problems involving primary or secondary knowledge contents.

Hypothesis 3a. Since secondary knowledge was assumed to consume more cognitive resources, adding a cognitive load with a second task should impede secondary content to a greater extent than primary knowledge content specifically regarding performance.

Hypothesis 3b. Similarly, facing with conflict problem that increased the need for cognitive resources, performance should be lower for secondary knowledge content than for primary knowledge content. There should be no difference for non-conflict problems.

3. Experiment 1

3.1. Method

3.1.1. Participants

The participants were 146 university students in France (39 men, 107 women, mean age was 22 ± 5), approached by University Facebook groups. Participants estimated their level in mathematics at 51/100 (± 31) and they liked logic games at 63/100 (± 22).

3.1.2. Materials

Each participant read the following instructions:

We will now propose statements. These statements will be as follows:

*“All things that have an engine need oil,
Cars have an engine,
Therefore cars need oil.”*
The premises (first two lines) must be considered as true.
The conclusion (last line) should only be accepted if it follows logically from the premises.

For each statement, you will have to judge whether or not the different conclusions proposed follow logically from their premises.

Sixteen syllogisms were created, eight referred to primary knowledge (contents about food and animal characteristics) and eight referred to secondary knowledge (contents about grammar and mathematics). Of the eight problems of each type of knowledge, five presented a conclusion whose logical status conflicted with its believability (conflict syllogisms that may induce belief bias) and three presented a conclusion whose logical status was consistent with its believability. We were interested in the conflict or non-conflict nature of the problems which was built on the congruence or not of the logical validity and the empirical validity (beliefs). We therefore only used these two types of validity to build syllogisms but did not detail their effects separately. Each syllogism consisted of a universal affirmative first premise as well as a particular affirmative second premise and conclusion. Here are some examples of syllogisms used in the experiment (translated from French; see [Appendix A](#) for all types of problems used):

Primary knowledge contents (noted “K1” in results):
*All human beings have two hands,
Men have two hands,
Therefore men are human beings* (conflict: invalid logical status and believable conclusion).

*All pizzas are high in fat,
The 5 cheeses is a pizza,
Therefore the 5 cheeses is high in fat* (non-conflict: valid logical status and believable conclusion).

Secondary knowledge contents (noted “K2” in results):
*All French adjectives in the feminine end in -e,
“Jolie” ends in -e,
Therefore “jolie” is a French adjective in the feminine* (conflict: invalid logical status and believable conclusion).

*All isosceles triangles have two sides of the same length,
Equilateral triangles are isosceles ones,
Therefore the equilateral triangles have two sides of the same length* (non-conflict: valid logical status and believable conclusion).

Participants responded to each syllogism by checking the box “the conclusion follows logically from the premises” or the box “the conclusion does not follow logically from the premises”. The basic abstract structure of problems were the same for primary and secondary information but the former was predicted to be more engaging and easier to solve.

Pre-tests were carried out to check that the type of knowledge used in the syllogisms did not influence the familiarity of the known terms ($n = 55$, results showed no difference in familiarity between primary ($M = 6.6/7$, $SD = 0.7$) and secondary knowledge ($M = 6.7/7$, $SD = 0.7$) ($t(54) = -0.26$, $p = 0.79$) nor the believability of the conclusion ($n = 50$, $t(49) = -0.14$, $p = 0.88$).

The added cognitive load was manipulated between groups by reversing the words in the syllogism. By asking participants to read in an unusual way, the extrinsic cognitive load of the task was higher than if words were presented in the conventional order. Participants in the high cognitive load modality (noted “CL high” in results) were confronted with syllogisms with reversed words. The following example resumes the first primary knowledge example cited above:

*Hands two have beings human all,
Hands two have men,
Beings human are men therefore.*

The participants were told to read the reversed words sentences from the right to the left for each line. Participants in the low cognitive load modality (noted “CL low” in results) read words in the conventional order.

3.1.3. Procedure

The experiment was conducted online with Qualtrics and 20 min long. Each participant was presented with eight syllogisms involving primary knowledge and eight syllogisms involving secondary knowledge; four syllogisms on each page. The presentation order was counterbalanced: half of the participants were presented with primary knowledge first (noted “K1 first” in results) and the other half were presented with secondary knowledge first (noted “K2 first” in results). On each page, the syllogisms were presented randomly in relation to their conflictual or non-conflictual nature.

Performance was recorded in percentage of correct responses. In addition, for each page and after completing four syllogisms, participants had to provide information on an analogic visual scale (from 0 to 100): How much they (i) “enjoy thinking about the questions” (emotional investment); How much they (ii) “wanted to find the correct answers” (cognitive investment/motivation); How much they were (iii) “confident about their given answers” (confidence); and How much they agreed with two sentences (iv) “the subject was complex” and “you concentrated a lot to do the task” (perceived cognitive load). The (v) speed (number of problems solved in 1 min) to complete each page was also measured. For each knowledge type, these variables were measured twice and their scores were averaged to be discussed in the analyses.

At the end of the experiment, a last sheet was added, similar to other syllogisms sheets: it showed two syllogisms that take the form of the syllogisms used during the experiment but in a more abstract way by replacing the terms with ABC (“A is B, C is B, therefore C is A” invalid and “A is B, C is A, therefore C is B” valid). In the same way as in the main experimental task, performance and all variables were measured on this page. Then, in order to assess the overall cognitive load on the whole experiment, a question asked participants how well they agree with the proposals “the topics covered were complex”, “you concentrated a lot on this study” and “the study was very easy for you”. These latter questions should allow to assess the effect of the presentation order of the two knowledge types and the impact of the added cognitive load on the overall experiment.

Finally, participants responded to some personal information including their estimated level in mathematics and their enthusiasm for solving logical problems.

3.1.4. Data analyses

A question allowed the participants to inform us that they made a break for more than 30 s during their run: 124 participants did not take a break, so we excluded the other 22 participants when the tested variable was speed. Linear mixed-effects models were used to analyze data. The Wald χ^2 , estimate and its Standard Error (SE) were reported for main analyses. In a minor way, between subjects' ANOVA (last ABC problems) were used. Means were noted M and standard deviation (\pm). All variables were scaled for analyses and performed with R 3.3.2. Non-significant results were not presented unless otherwise specified.

3.2. Results

3.2.1. The two knowledge types

Compared with secondary knowledge, primary knowledge elicited higher performance and enjoyment in performing the task and reduced the perceived cognitive load. Marginally, primary knowledge increased confidence in given answers ([Table 1](#)).

3.2.2. Presentation order

The presentation order did not influence overall data. It only influenced primary knowledge content problems ($\chi^2 = 22.17$, $p < 0.001$ for interaction): the enjoyment in performing the task ($M_{K1first} = 68.0 \pm 25.0$ vs. $M_{K2first} = 58.0 \pm 28.2$) (estimate = -0.39 , SE = 0.15 ; $\chi^2 = 6.74$, $p = 0.01$) was greater when primary knowledge contents were presented first, whereas regarding secondary knowledge content problems, the presentation order had no influence.

Table 1

Results from linear mixed-effects models regarding the influence of the two knowledge types on the dependent variables in Experiment 1. Analysis were described with means (M), standard deviation (SD) and standard error of the estimate (SE).

	Primary knowledge		Secondary knowledge		Estimate	SE	χ^2	p
	M	SD	M	SD				
Performance	73.9	33.5	63.2	32.1	-0.32	0.06	31.33	<0.001
Enjoy answering questions	63.0	27.1	59.1	26.3	-0.14	0.04	10.87	0.001
Want to find the correct answers	66.7	24.8	66.2	25.9	-0.02	0.04	0.18	0.67
Confidence	59.9	27.5	57.4	27.8	-0.09	0.05	3.50	0.06
Perceived cognitive load	35.9	21.3	40.4	21.1	0.09	0.04	20.28	<0.001
Speed (pb/min) (n = 124)	5.1	10.8	5.1	10.9	0.001	0.09	<0.001	0.99

3.2.3. The influence of added cognitive load and problem type (conflict/non-conflict) on the two knowledge types

Regarding the simple effect of the added cognitive load, when the added cognitive load was low, the speed of task resolution was greater ($estimate = -0.25$, $SE = 0.12$; $\chi^2 = 5.45$, $p = 0.02$) ($M_{CL\ low} = 6.3 \pm 12.6$ vs. $M_{CL\ high} = 4.0 \pm 8.7$), which validated the reversed words task effect. Non-conflict syllogisms ($M = 82.1 \pm 22.6$) led to higher performance than conflict syllogisms ($M = 55.0 \pm 36.4$) ($estimate = -0.82$, $SE = 0.06$; $\chi^2 = 205.51$, $p < 0.001$). The interaction between the syllogism type and the added cognitive load was not significant ($\chi^2 = 2.31$, $p = 0.12$). The interaction effect between the syllogism type and the knowledge type ($\chi^2 = 14.83$, $p < 0.001$) reflected a significant impact of the knowledge type on the performance in non-conflict syllogisms ($M_{K1} = 91.0 \pm 17.6$ vs. $M_{K2} = 73.2 \pm 23.6$) ($estimate = -0.78$, $SE = 0.09$; $\chi^2 = 81.29$, $p < 0.001$) but not on the performance in conflict syllogisms ($M_{K1} = 56.7 \pm 36.6$ vs. $M_{K2} = 53.2 \pm 36.2$) ($estimate = -0.09$, $SE = 0.06$; $\chi^2 = 2.74$, $p = 0.10$). Non-conflict syllogisms led to higher performance in both primary ($M_{non-conflict} = 91.0 \pm 17.6$ vs. $M_{conflict} = 56.7 \pm 36.6$) ($estimate = -1.03$, $SE = 0.09$; $\chi^2 = 125.43$, $p < 0.001$) and secondary knowledge ($M_{non-conflict} = 73.2 \pm 23.6$ vs. $M_{conflict} = 53.2 \pm 36.2$) ($estimate = -0.62$, $SE = 0.09$; $\chi^2 = 49.51$, $p < 0.001$).

3.2.4. Additional analyses: the ABC problems and the total subjective cognitive load

Results regarding the latest ABC problems did not show a significant influence of the presentation order of the two knowledge types. The added cognitive load marginally influenced the confidence in given responses ($M_{CL\ low} = 67.5 \pm 29.2$ vs. $M_{CL\ high} = 58.7 \pm 28.2$) ($F(1,142) = 3.51$, $p = 0.06$, $\eta_p^2 = 0.02$). However, there was no effect on the overall perceived cognitive load.

3.2.5. Discussion

Experiment 1 partially corroborated our **Hypothesis 1**: compared with secondary knowledge presentation of logical problems, primary knowledge presentation increased performance, emotional investment and decreased perceived cognitive load. **Hypothesis 2**: it appeared that presenting secondary knowledge first would undermine participants' emotional investment in primary knowledge content problems, while the presentation order of knowledge did not influence responses to secondary knowledge content problems. This could be an argument in favor of secondary knowledge not being very motivating. **Hypothesis 3b**: results also highlighted an unexpected result regarding the interaction between the knowledge type and the syllogism type. Contrary to what was expected, the knowledge type seemed to influence performance for non-conflict problems and not for conflict problems.

4. Experiment 2

Experiment 2 replicated Experiment 1 to confirm the positive effect of primary knowledge versus secondary knowledge on performance that would be higher in non-conflict syllogisms than in conflict syllogisms.

4.1. Method

4.1.1. Participants

The participants were 147 university students in France (27 men, 120 women, mean age was 20 ± 3), approached by University Facebook groups. Participants estimated their level in mathematics at 43/100 (± 29) and they liked logic games at 62/100 (± 19).

4.1.2. Materials, procedure and data analyses

Material, procedure and data analyses were similar to those of Experiment 1. Data showed that 123 participants did not take a break, so we excluded the other 24 participants when the tested variable was speed.

4.2. Results

4.2.1. The two knowledge types

Compared with secondary knowledge, primary knowledge elicited higher performance, enjoyment in performing the task, wish to find the correct answers and confidence in given responses as well as a lower perceived cognitive load (Table 2).

4.2.2. Presentation order

The presentation order did not influence overall data. The interaction between the presentation order and the knowledge type was significant regarding the enjoyment in performing the task ($\chi^2 = 27.09$, $p < 0.001$), the wish to find the correct answers ($\chi^2 = 69.54$, $p < 0.001$) and the perceived cognitive load ($\chi^2 = 12.65$, $p < 0.001$). These interactions reflected a greater impact of the presentation order on primary knowledge contents compared with secondary knowledge contents: regarding primary knowledge contents, when primary knowledge was presented first, participants enjoyed answering questions ($M_{K1\ first} = 64.3 \pm 24.3$ vs. $M_{K2\ first} = 52.4 \pm 25.4$) ($estimate = -0.47$, $SE = 0.15$; $\chi^2 = 9.09$, $p = 0.003$) and wanted to find the correct answer in a higher way ($M_{K1\ first} = 71.4 \pm 21.2$ vs. $M_{K2\ first} = 60.3 \pm 25.0$) ($estimate = -0.45$, $SE = 0.16$; $\chi^2 = 7.95$, $p = 0.005$). The perceived cognitive load was also lower when primary knowledge was presented first ($M_{K1\ first} = 41.1 \pm 22.2$ vs. $M_{K2\ first} = 32.8 \pm 17.7$) ($estimate = -0.44$, $SE = 0.15$; $\chi^2 = 8.39$, $p = 0.004$).

4.2.3. The influence of added cognitive load and problem type (conflict/non-conflict) on the two knowledge types

Results did not show a main effect of the added cognitive load. Non-conflict syllogisms ($M = 78.2 \pm 25.5$) led to higher performance than conflict syllogisms ($M = 44.6 \pm 33.5$) ($estimate = -0.98$, $SE = 0.06$; $\chi^2 = 266.37$, $p < 0.001$). The interaction between the syllogism type and the added cognitive load was not significant ($\chi^2 = 0.18$, $p = 0.67$). The interaction effect between the syllogism type and the knowledge type ($\chi^2 = 23.35$, $p < 0.001$) reflected a significant impact of the knowledge type on the performance in non-conflict syllogisms ($M_{K1} = 88.8 \pm 22.1$ vs. $M_{K2} = 67.5 \pm 24.3$) ($estimate = -0.83$, $SE = 0.08$; $\chi^2 = 91.52$, $p < 0.001$) but not on the performance in conflict syllogisms ($M_{K1} = 45.5 \pm 34.9$ vs. $M_{K2} = 43.6 \pm 32.1$) ($estimate = -0.06$, $SE = 0.06$; $\chi^2 = 0.87$, $p =$

Table 2

Results from linear mixed-effects models regarding the influence of the two knowledge types on the dependent variables in Experiment 2. Analysis were described with means (M), standard deviation (SD) and standard error of the estimate (SE).

	Primary knowledge		Secondary knowledge		Estimate	SE	χ^2	p
	M	SD	M	SD				
Performance	67.2	36.3	55.6	30.9	−0.34	0.06	31.79	<0.001
Enjoy answering questions	58.2	25.5	52.4	25.9	−0.22	0.05	19.48	<0.001
Want to find the correct answers	65.7	23.8	61.9	25.0	−0.15	0.05	9.61	0.002
Confidence	53.8	28.3	49.6	27.7	−0.15	0.05	9.29	0.002
Perceived cognitive load	36.9	20.4	40.0	21.7	0.15	0.05	9.56	0.002
Speed (pb/min) (n = 123)	6.3	12.4	4.7	9.2	0.14	0.09	2.38	0.12

0.35). Non-conflict syllogisms led to higher performance in both primary ($M_{\text{non-conflict}} = 88.8 \pm 22.1$ vs. $M_{\text{conflict}} = 45.5 \pm 34.9$) ($\text{estimate} = -1.19$, $\text{SE} = 0.09$; $\chi^2 = 166.92$, $p < 0.001$) and secondary knowledge ($M_{\text{non-conflict}} = 67.5 \pm 24.3$ vs. $M_{\text{conflict}} = 43.67 \pm 32.18$) ($\text{estimate} = -0.77$, $\text{SE} = 0.09$; $\chi^2 = 69.10$, $p < 0.001$).

4.2.4. Additional analyses: the ABC problems and the total subjective cognitive load

Regarding the responses to the last ABC problems, participants enjoyed answering questions more ($M_{K1\text{first}} = 52.8 \pm 26.8$ vs. $M_{K2\text{first}} = 42.7 \pm 27.1$) ($F(1,143) = 5.01$, $p = 0.03$, $\eta_p^2 = 0.03$) and were more confident ($M_{K1\text{first}} = 59.0 \pm 28.7$ vs. $M_{K2\text{first}} = 45.0 \pm 30.6$) ($F(1,143) = 8.27$, $p = 0.005$, $\eta_p^2 = 0.05$) when primary contents were presented first. The added cognitive load influenced the perceived cognitive load during the last ABC problems ($M_{\text{CL low}} = 47.3 \pm 20.4$ vs. $M_{\text{CL high}} = 37.2 \pm 24.1$) ($F(1,143) = 7.45$, $p = 0.007$, $\eta_p^2 = 0.05$): participants considered that ABC problems were less difficult and demanded in terms of working memory resources than syllogisms with reversed words.

4.2.5. Discussion

Hypothesis 1: Experiment 2 confirmed the positive influence of primary knowledge presentation of logical problems on all the studied variables. It also reinforced our arguments in favor of secondary knowledge presentation having an effect that undermined participants' motivation and increased the perceived cognitive load for normally motivating problems (primary knowledge contents). **Hypothesis 2:** presenting primary knowledge first seemed to be positive and to increase enjoyment in performing the task as well as the confidence in responses in the final ABC problems. **Hypothesis 3b:** Experiment 2 replicated the results of Experiment 1 regarding the interaction between the knowledge type and the syllogism type (non-conflict vs. conflict). The first two possible way of explanation could be as follows:

- Regarding the fact that performance did not differ according to the knowledge type for conflict problems, it was likely that this outcome was related to the nature of the task which confounded, to some extent, the measurement of judgments about primary knowledge contents. Indeed, judging the validity of a conclusion could depend on the treatment of secondary knowledge (Stano-vich & West, 2000). In the present task, the content was masked into primary or secondary knowledge, but the essential task was to deal with secondary knowledge (formal logic) that made no difference for conflict problems as it involved mobilizing cognitive resources. Most people would need some instruction on how to make these decontextualized judgments, and this could be why the differences between primary and secondary contents were not as large for conflict problems.
- Regarding the higher performance of primary versus secondary contents for non-conflict problems, it could be argued that secondary knowledge involved a specific cognitive load linked to the detection of its nature, in addition to the cognitive load required for it to be processed. Indeed, when participants were faced with secondary knowledge, they often become demotivated and did

not feel able to process it even before they had tried it (Braver et al., 2014; Cosnefroy et al., 2016). In a third experiment, we wanted to test the impact of the types of knowledge and syllogisms on all variables and to verify, for example, whether participants felt more demotivated or less confident about non-conflict syllogisms whose content was related to secondary knowledge than those whose content was related to primary knowledge.

5. Experiment 3

Experiment 3 aimed to confirm the main assumptions by broadening the observations on the influence of the syllogism type beyond performance in order to better understand the mechanisms involved.

5.1. Method

5.1.1. Participants

The participants were 204 university students in France (25 men, 179 women, mean age was 19 ± 2), approached by University Facebook groups. Participants estimated their level in mathematics at 47/100 (± 29) and they liked logic games at 70/100 (± 26).

5.1.2. Materials, procedure and data analyses

Material and procedure were similar to those of experiments 1 and 2 except for two differences. First, instead of using five conflict and three non-conflict syllogisms per type of knowledge, we created four of each. Second, the syllogisms were presented by type of knowledge but also by type of syllogism: on a page of four syllogisms, the participants read either conflict syllogisms or non-conflict syllogisms in order to collect data on the set of all dependent variables (enjoy answering questions, want to find the correct answer, confidence and perceived cognitive load) and not only on performance.

Analyses were the same as in the first experiments. Data showed that 177 participants did not take a break, so we excluded the other 27 participants when the tested variable was speed.

5.2. Results

5.2.1. The two knowledge types

Compared with secondary knowledge, primary knowledge elicited higher performance, enjoyment in performing the task and confidence in given responses as well as a lower perceived cognitive load. Primary knowledge marginally increased the wish to find the correct answers (Table 3).

5.2.2. Presentation order

Participants had better overall performance when primary knowledge problems were presented first ($M_{K1\text{first}} = 59.1 \pm 34.8$ vs. $M_{K2\text{first}} = 53.0 \pm 36.1$) ($\text{estimate} = -0.18$, $\text{SE} = 0.07$; $\chi^2 = 5.95$, $p = 0.01$). The interaction between the knowledge type and the presentation order was significant for the enjoyment in performing the task ($\chi^2 = 21.51$, $p < 0.001$) and the wish to find the correct answers ($\chi^2 = 37.08$, $p < 0.001$).

Table 3

Results from linear mixed-effects models regarding the influence of the two knowledge types on the dependent variables in Experiment 3. Analysis were described with means (M), standard deviation (SD) and standard error of the estimate (SE).

	Primary knowledge		Secondary knowledge		Estimate	SE	χ^2	p
	M	SD	M	SD				
Performance	64.4	35.8	47.4	33.4	-0.48	0.05	90.87	<0.001
Enjoy answering questions	59.6	26.3	56.4	26.3	-0.12	0.04	7.55	0.006
Want to find the correct answers	67.1	23.9	65.0	24.5	-0.08	0.05	3.21	0.07
Confidence	55.8	27.8	52.8	28.3	-0.10	0.04	6.26	0.01
Perceived cognitive load	40.4	22.0	42.9	20.4	0.12	0.04	7.66	0.006
Speed (pb/min) (n = 177)	5.7	10.9	4.8	9.9	-0.03	0.07	0.21	0.64

The presentation order had a significant influence on primary knowledge contents only: participants enjoyed performing the task ($M_{K1\text{first}} = 64.7 \pm 22.5$ vs. $M_{K2\text{first}} = 54.9 \pm 28.7$) ($\text{estimate} = -0.39$, $\text{SE} = 0.13$; $\chi^2 = 8.61$, $p = 0.003$) and wanted to find the correct answers ($M_{K1\text{first}} = 70.6 \pm 20.4$ vs. $M_{K2\text{first}} = 63.7 \pm 26.4$) ($\text{estimate} = -0.30$, $\text{SE} = 0.13$; $\chi^2 = 5.37$, $p = 0.02$) more when these problems were presented first.

5.2.3. The influence of added cognitive load and problem type (conflict/non-conflict) on the two knowledge types

The high added cognitive load modality tended to decrease performance ($M_{\text{CL low}} = 58.5 \pm 35.0$ vs. $M_{\text{CL high}} = 53.4 \pm 36.1$) ($\text{estimate} = -0.13$, $\text{SE} = 0.07$; $\chi^2 = 3.23$, $p = 0.07$) but had no influence on the other variables. Non-conflict syllogisms ($M = 74.5 \pm 26.2$) led to higher performance than conflict syllogisms ($M = 37.3 \pm 34.1$) ($\text{estimate} = -1.14$, $\text{SE} = 0.09$; $\chi^2 = 445.01$, $p < 0.001$). The interaction between the syllogism type and the added cognitive load was marginally significant ($\chi^2 = 2.92$, $p = 0.08$): faced with non-conflict syllogisms, the added cognitive load did not influence performance ($M_{\text{CL low}} = 75.6 \pm 26.3$ vs. $M_{\text{CL high}} = 73.5 \pm 26.2$) ($\text{estimate} = -0.07$, $\text{SE} = 0.10$; $\chi^2 = 0.50$, $p = 0.48$) whereas faced with conflict syllogisms, the high added cognitive load modality ($M = 33.4 \pm 33.4$) tended to decrease performance compared with the low added cognitive load modality ($M = 41.5 \pm 34.4$) ($\text{estimate} = -0.22$, $\text{SE} = 0.12$; $\chi^2 = 3.28$, $p = 0.07$).

The interaction effect between the syllogism type and the knowledge type ($\chi^2 = 13.36$, $p < 0.001$) reflected a greater impact of the knowledge type on the performance in non-conflict syllogisms ($M_{K1} = 86.2 \pm 20.2$ vs. $M_{K2} = 62.8 \pm 26.4$) ($\text{estimate} = -0.89$, $\text{SE} = 0.08$; $\chi^2 = 133.38$, $p < 0.001$) than on the performance in conflict syllogisms ($M_{K1} = 42.6 \pm 34.8$ vs. $M_{K2} = 32.1 \pm 32.6$) ($\text{estimate} = -0.31$, $\text{SE} = 0.06$; $\chi^2 = 27.08$, $p < 0.001$) (Fig. 1). Non-conflict syllogisms led to higher performance in both primary ($M_{\text{non-conflict}} = 86.2 \pm 20.2$ vs. $M_{\text{conflict}} = 42.6 \pm 34.8$) ($\text{estimate} = -1.22$, $\text{SE} = 0.08$; $\chi^2 = 242.26$, $p < 0.001$) and secondary knowledge ($M_{\text{non-conflict}} = 62.8 \pm 26.4$ vs. $M_{\text{conflict}} = 32.1 \pm 32.6$) ($\text{estimate} = -0.92$, $\text{SE} = 0.07$; $\chi^2 = 152.84$, $p < 0.001$).

The interaction between the syllogism type and the knowledge type was marginally significant regarding the enjoyment of performing the task ($\chi^2 = 2.85$, $p = 0.09$) and the perceived cognitive load ($\chi^2 = 3.07$, $p = 0.07$). Regarding secondary knowledge content problems only, conflict syllogisms elicited higher enjoyment ($M_{\text{non-conflict}} = 54.5 \pm 27.5$ vs. $M_{\text{conflict}} = 58.2 \pm 25.1$) ($\text{estimate} = 0.14$, $\text{SE} = 0.06$; $\chi^2 = 6.14$, $p = 0.01$) whereas they did not influence the enjoyment regarding primary knowledge content problems. Regarding primary knowledge content problems only, non-conflict syllogisms led to lower perceived cognitive load compared with conflict syllogisms ($M_{\text{non-conflict}} = 38.8 \pm 21.4$ vs. $M_{\text{conflict}} = 41.9 \pm 22.4$) ($\text{estimate} = 0.14$, $\text{SE} = 0.05$; $\chi^2 = 6.98$, $p = 0.008$) whereas the syllogism type did not seem to influence the perceived cognitive load regarding secondary knowledge contents.

5.2.4. Additional analyses: the ABC problems and the total subjective cognitive load

The added cognitive load influenced the perceived cognitive load during the last ABC problems ($M_{\text{CL low}} = 55.4 \pm 26.9$ vs. $M_{\text{CL high}} = 44.7 \pm 22.3$) ($F(1,200) = 9.54$, $p = 0.002$, $\eta_p^2 = 0.04$): participants considered

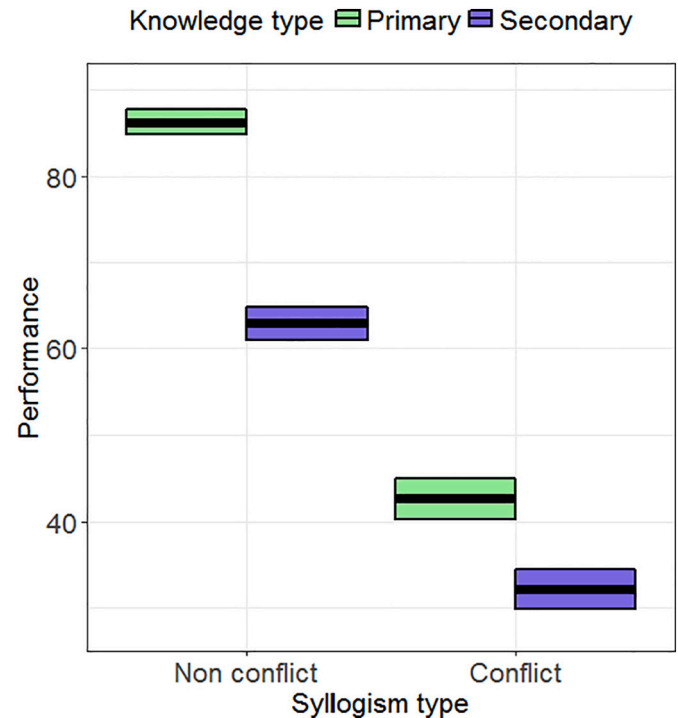


Fig. 1. Experiment 3. Interaction between the syllogism type and the knowledge on participants' performance (boxplots represented the mean and 95% of the confidence interval).

that ABC problems were less difficult and demanded in terms of working memory resources than syllogisms with reversed words.

5.2.5. Discussion

Hypothesis 1: Experiment 3 confirmed again the positive influence of primary knowledge presentation on most variables of interest. The results also reinforced the argument of **Hypothesis 2** that presenting problems with secondary knowledge content first would undermine participants' motivation even on problems that were supposed to be intrinsically motivating (primary knowledge contents). In addition, presenting primary knowledge first would promote overall performance on the experimental task.

Moreover, results showed that performance was always higher for primary knowledge compared with secondary knowledge, regardless of the syllogism type. This difference in performance was higher for non-conflict syllogisms compared with conflict ones. This argued in favor of the existence of a cognitive load linked to the nature of secondary knowledge which may be different from a cognitive load linked to it to be processed. Secondary knowledge would therefore lead to a kind of conflict sensation that would not be sufficient to trigger or end the action of system 2 and produce the correct answer. This explanation might be supported by the fact that the effect of the syllogism type on perceived

(subjective) cognitive load was only showed for primary knowledge contents: participants felt “correctly” the conflict for conflict problems. This result would imply that, regarding secondary knowledge contents, the cognitive load experienced was always the same, whether or not there was a conflict: participants had a sense of conflict even when it was not relevant (non-conflict syllogisms). Participants seemed to experience a cognitive load linked to conflict (that may induce belief bias) and to secondary knowledge. However, these two loads did not add up: as soon as there was a conflicting sensation (whatever the source), a cognitive load was assigned. Finally, perceiving conflict seemed to motivate participants only in the context of secondary knowledge contents. In this experiment, participants reported that they liked logic games and seemed interested in being challenged. This motivation would only affect secondary knowledge since primary knowledge did not require additional motivation to engage participants.

Surprisingly, just like the first two experiments, this third one did not replicate (or marginally) the classic interaction between the syllogism type and the added cognitive load. This lack of effect may be related to the counterbalancing of the primary knowledge effect but also to the cognitive load task chosen. In fact, reversing the order of words in syllogisms was a task intrinsic to the problem and may not generate the same type or amount of cognitive load that would hinder the action of system 2 as the literature stated. Experiment 4 proposed to test the results obtained by interviewing younger participants and using a Dot Memory Task that was classic in reasoning studies.

6. Experiment 4

The goal of experiment 4 was to consolidate the previous results by challenging them with another task well-known to diminish working memory resources: the Dot Memory Task (Bethell-Fox & Shepard, 1988; De Neys, 2006; Miyake et al., 2001). Moreover, several studies showed that adolescents (especially older adolescents) did not reason in a highly different way compared with adults (Khemlani & Johnson-Laird, 2012; Markovits & Lortie-Forgues, 2011). Thus, we wanted to challenge the evolutionary approach of knowledge with younger participants as much, if not more, subject to demotivation regarding secondary knowledge.

6.1. Method

6.1.1. Participants

The participants were 102 students from high school (46 boys, 56 girls, mean age was 14 ± 1). Their estimated their level in mathematics at 55/100 (± 25), they like logic games at 66/100 (± 28) and 76% ($n = 78$) never played (or very little) logic games.

6.1.2. Materials

The same presentation of the syllogisms as in Experiment 3 was used but instead of a reversed word task to manipulate the cognitive load, a Dot Memory Task was used in order to replicate Experiment 1's results and challenge our assumptions (*cf.* Procedure).

6.1.3. Procedure

The procedure was similar to that of Experiment 3, except for two changes. First, the experiment was a paper-pencil one during school time. Second, a Dot Memory Task protocol was applied. Before each sheet of four syllogisms and analogic visual scale, participants had to memorize the position of several dots in a table (3×3) projected on the blackboard during 850 milliseconds. After answering each question on the sheet, they had to fill in a table with the dots remembered on the next sheet. The aim was to load working memory while answering questions. Participants in the high cognitive load modality had to remember a four dots pattern (of which two maximum were side-by-side) and participants in the low cognitive load modality had to remember a 3 aligned dots pattern (Fig. 2). Each participant had 4 min to complete questions and have to wait to go to the next page and fill in the table. Thus the speed was not measured.

6.1.4. Data analyses

Statistical analyzes were similar to those of previous experiments. In a minor way, ANOVA were used to investigate in detail the triple interaction between the knowledge type, the syllogism type and the added cognitive load modality. Between and within *t*-tests as well as Pearson correlations were used to analyze the Dot Memory Task performances.

6.2. Results

6.2.1. The two knowledge types

Compared with secondary knowledge, primary knowledge elicited higher performance and confidence in given responses as well as a lower perceived cognitive load. It also tended to lead to higher enjoyment in performing the task (Table 4).

6.2.2. Presentation order

Across the main task, when primary knowledge contents were presented first, participants enjoyed answering questions in a higher way ($M_{K1first} = 60.4 \pm 28.3$ vs. $M_{K2first} = 51.0 \pm 28.7$) ($estimate = -0.35$, $SE = 0.17$; $\chi^2 = 4.16$, $p = 0.04$) and were more confident ($M_{K1first} = 63.2 \pm 28.3$ vs. $M_{K2first} = 48.1 \pm 30.2$) ($estimate = -0.48$, $SE = 0.15$; $\chi^2 = 9.65$, $p = 0.002$).

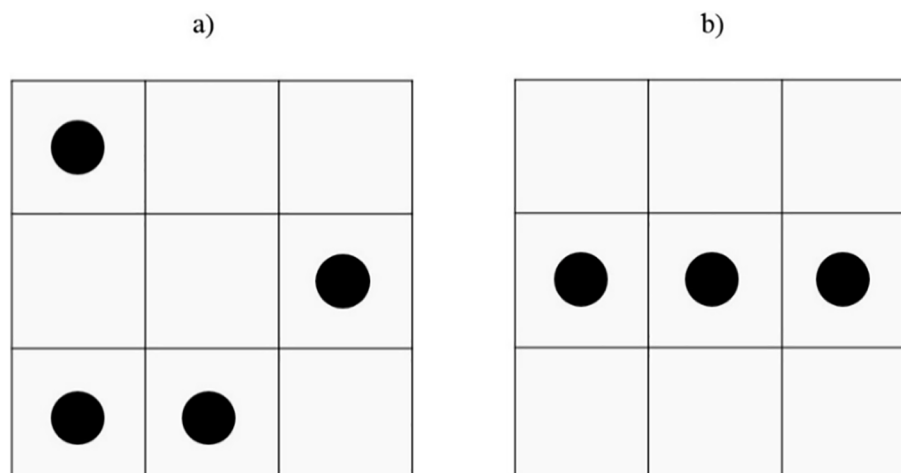


Fig. 2. Examples of Dot Memory Task patterns regarding a) the high cognitive load modality and b) the low cognitive load modality.

Table 4

Results from linear mixed-effects models regarding the influence of the two knowledge types on the dependent variables in Experiment 4. Analysis were described with means (M), standard deviation (SD) and standard error of the estimate (SE).

	Primary knowledge		Secondary knowledge		Estimate	SE	χ^2	p
	M	SD	M	SD				
Performance	59.9	32.2	44.1	26.3	-0.52	0.08	41.88	<0.001
Enjoy answering questions	57.2	38.7	54.2	29.0	-0.10	0.05	3.38	0.06
Want to find the correct answers	69.3	26.7	67.2	26.9	-0.08	0.05	1.87	0.17
Confidence	58.5	30.2	52.9	30.0	-0.18	0.05	11.44	<0.001
Perceived cognitive load	38.0	23.9	40.7	23.9	0.11	0.06	3.76	0.05

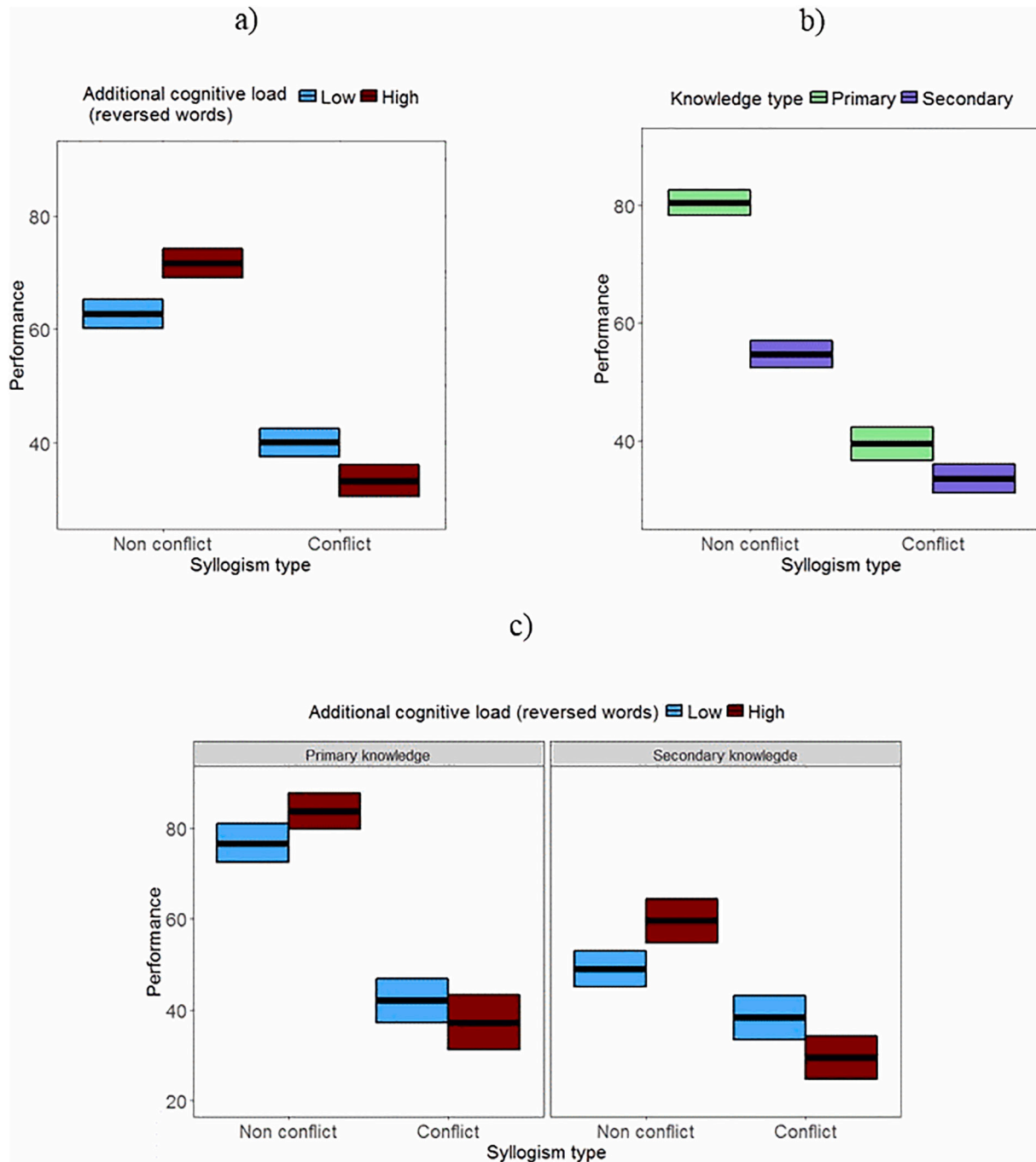


Fig. 3. Experiment 4. Interactions between the syllogism type and a) the added cognitive load, b) the knowledge type and c) the added cognitive load and the knowledge type on participants' performance (boxplots represented the mean and 95% of the confidence interval).

6.2.3. The influence of added cognitive load and problem type (conflict/non-conflict) on the two knowledge types

Regarding the Dot Memory Task, participants had higher performance when the pattern was simple (low cognitive load modality ($97.8\% \pm 11.3$) than when the pattern was complex (high cognitive load modality ($65.4\% \pm 25.0$) ($t(100) = 17.23$, $p < 0.001$). The knowledge type did not influence success rate in the Dot Memory Task ($ps > 0.30$). The performance in the Dot Memory Task was positively correlated to the performance of the experimental task whatever the knowledge type (primary knowledge $r = 0.18$, $p < 0.001$; secondary knowledge $r = 0.1$, $p = 0.05$) indicating that the participants did not skip any task.

The high cognitive load modality decreased the confidence in given responses ($M_{CL\ low} = 62.2 \pm 29.6$ vs. $M_{CL\ high} = 50.2 \pm 29.6$) ($estimate = -0.33$, $SE = 0.15$; $\chi^2 = 4.51$, $p = 0.04$). Non-conflict syllogisms ($M = 67.5 \pm 25.7$) led to higher performance than conflict syllogisms ($M = 36.5 \pm 26.6$) ($estimate = -1.02$, $SE = 0.08$; $\chi^2 = 161.08$, $p < 0.001$).

The interaction between the syllogism type and the added cognitive load was significant ($\chi^2 = 11.00$, $p = 0.001$): the high added cognitive load modality increased the performance in non-conflict syllogisms ($M_{CL\ low} = 62.7 \pm 25.0$ vs. $M_{CL\ high} = 71.5 \pm 25.6$) ($estimate = 0.32$, $SE = 0.13$; $\chi^2 = 6.26$, $p = 0.01$) and tended to decrease the performance in conflict syllogisms ($M_{CL\ low} = 40.1 \pm 24.9$ vs. $M_{CL\ high} = 33.4 \pm 27.7$) ($estimate = -0.29$, $SE = 0.17$; $\chi^2 = 2.78$, $p = 0.09$) (Fig. 3a).

The interaction effect between the syllogism type and the knowledge type ($\chi^2 = 17.40$, $p < 0.001$) reflected a greater impact of the knowledge type on the performance in non-conflict syllogisms ($M_{K1} = 80.3 \pm 21.0$ vs. $M_{K2} = 54.6 \pm 23.5$) ($estimate = -1.00$, $SE = 0.11$; $\chi^2 = 87.40$, $p < 0.001$) than on the performance in conflict syllogisms ($M_{K1} = 39.4 \pm 28.2$ vs. $M_{K2} = 33.5 \pm 24.7$) ($estimate = -0.22$, $SE = 0.09$; $\chi^2 = 6.18$, $p = 0.01$) (Fig. 3b). Non-conflict syllogisms led to higher performance in both primary ($M_{non-conflict} = 80.3 \pm 21.0$ vs. $M_{conflict} = 39.4 \pm 28.3$) ($estimate = -1.27$, $SE = 0.11$; $\chi^2 = 139.04$, $p < 0.001$) and secondary knowledge ($M_{non-conflict} = 54.6 \pm 23.5$ vs. $M_{conflict} = 33.5 \pm 24.7$) ($estimate = -0.80$, $SE = 0.13$; $\chi^2 = 39.06$, $p < 0.001$).

The interaction between the added cognitive load and the syllogism type was not significant for primary knowledge contents ($F(1,98) = 2.89$, $p = 0.09$) but significant for secondary knowledge contents ($F(1,98) = 8.72$, $p = 0.004$) (Fig. 3c). Regarding secondary knowledge content problems, a high added cognitive load modality increased the performance in non-conflict problems ($M_{CL\ low} = 48.9 \pm 20.1$ vs. $M_{CL\ high} = 59.5 \pm 25.2$) ($F(1,100) = 6.05$, $p = 0.01$, $\eta_p^2 = 0.06$) and marginally decreased the performance in conflict problems ($M_{CL\ low} = 38.3 \pm 24.9$ vs. $M_{CL\ high} = 29.5 \pm 24.1$) ($F(1,100) = 3.32$, $p = 0.07$, $\eta_p^2 = 0.03$). The syllogism type did not significantly influence any other variable of interest.

6.2.4. Additional analyses: the level in mathematics and last problems ABC

ABC problems were marginally more successful when the added cognitive load modality was high ($M_{CL\ low} = 47.8 \pm 23.0$ vs. $M_{CL\ high} = 56.3 \pm 21.4$) ($F(1,98) = 3.57$; $p = 0.06$; $\eta_p^2 = 0.04$) that may indicate participants' stronger involvement face with a complex pattern of Dot Memory Task. The overall perceived cognitive load was higher when the added cognitive load modality was high ($M_{CL\ low} = 34.6 \pm 22.5$ vs. $M_{CL\ high} = 46.5 \pm 18.2$) ($F(1,98) = 10.02$; $p = 0.002$; $\eta_p^2 = 0.09$) validating the Dot Memory Task procedure.

6.2.5. Discussion

Experiment 4 replicated previous results regarding the positive influence of primary knowledge presentation on most variables (Hypothesis 1) and the negative impact of presenting secondary knowledge first, which undermined the enjoyment in answering question and the confidence in given answers (Hypothesis 2). It also confirmed that, compared with secondary knowledge, primary knowledge promoted performance regardless of the syllogism type, but in a greater way for non-conflict syllogisms than for conflict ones. This result is an argument in favor of Hypothesis 3a/Hypothesis 3b that secondary knowledge

would require more cognitive resources to be processed (difference in performance between knowledge types for conflict problems). Secondary knowledge might also lead to a feeling of conflict/cognitive load related to the detection of its nature (higher difference in performance between knowledge types for non-conflict problems): secondary knowledge might lead participants to mistrust their first answers and seek to produce another ones. This sense of conflict would not be sufficient to activate the Type 2 response or would prevent Type 2 from completing its process since performance was lower. Experiment 4 also showed an interaction between the syllogism type and the added cognitive load: performance was higher for non-conflict problems when the added cognitive load modality was high (this result tended to be reversed for conflict problems). In general, this result illustrated what was observed during the experiment in classrooms: participants were much more concentrated when the Dot Memory Task was complex.

The beneficial influence of primary knowledge on all variables seemed to be robust in our experiments. Someone could argue that this effect may be due to the familiarity of primary knowledge. We therefore wanted to extend the field of validity of the results in a fifth experiment by minimizing as much as possible the access to previous knowledge.

7. Experiment 5

Experiment 5 aimed to check that the results of previous experiments were not simply due to an effect of previous knowledge by using unknown words in the syllogisms. It also sought to test the specific or more general characteristics of both knowledge types, with the current literature considering that primary knowledge was defined by being close to individuals in their direct environment (Geary, 2008; Roussel et al., 2017).

7.1. Method

7.1.1. Participants

The participants were 212 university students in France (39 men, 173 women, mean age was 19 ± 3), approached by University Facebook groups. Participants estimated their level in mathematics at 45/100 (± 21) and they liked logic games at 68/100 (± 26). None found the themes familiar.

7.1.2. Materials

Materials were based on those of Experiment 3. Four syllogisms were showed per sheet with the same response modalities, but this time, the syllogisms had a content that aimed to reduce as much as possible previous knowledge: the content used words that did not exist. In addition to the syllogisms composed of a universal affirmative first premise as well as a particular affirmative second premise and conclusion, syllogisms composed of a universal affirmative first premise as well as a particular negative second premise and conclusion were used. Here are some examples of syllogisms used in the experiment (see Appendix A for all types of problems used):

Primary knowledge contents (food and animal characteristics):

All ronvacs are wild and herbivorous,

Yellow horned cachuls are ronvacs,

Therefore yellow horned cachuls are wild and herbivorous (valid).

All loutas are sweet and juicy,

The white rouli is not a louta,

Therefore the white rouli is not sweet and juicy (invalid).

Secondary knowledge contents (grammar and mathematics):

All Foster equations are the type $x = \sqrt{(3b - 2ac)}$,

Jyrog formula is a Foster equation,

Therefore Jyrog formula is the type $x = \sqrt{(3b - 2ac)}$ (valid).

All Sendamin common names end in -li in the plural,

"Alda" is not a Sendamin common name,

Therefore "alda" does not end in -li in the plural (invalid) (cf. Appendix A.2 for every syllogism used).

As in Experiment 4, the added extraneous cognitive load was manipulated by reversing the order of words in the syllogisms.

7.1.3. Procedure

The procedure was similar to that of Experiment 3 with the exception of the conflict vs. non-conflict syllogism block allocation and the number of ABC syllogisms at the end of the experiment. Indeed, for this last syllogism sheet, we added two problems taking into account the negative versions added in this experiment (“A is B, C is not B, therefore C is not A” valid, “A is B, C is not A, therefore C is not B” invalid).

7.1.4. Data analyses

Analyses were the same as in Experiment 3. Data showed that 179 participants did not take a break, so we excluded the other 33 participants when the tested variable was speed.

7.2. Results

7.2.1. The two knowledge types

Compared with secondary knowledge, primary knowledge elicited higher performance, enjoyment in performing the task, wish to find the correct answers and confidence in given responses as well as a lower perceived cognitive load (Table 5).

7.2.2. Presentation order

Across the main task, when primary knowledge contents were presented first, participants were more confident in their responses ($M_{K1first} = 54.5 \pm 28.6$ vs. $M_{K2first} = 50.1 \pm 32.0$) ($estimate = -0.25$, $SE = 0.11$; $\chi^2 = 4.75$, $p = 0.03$). The interaction between the knowledge type and the presentation order was significant for the enjoyment in performing the task ($\chi^2 = 14.96$, $p < 0.001$) and the wish to find the correct answers ($\chi^2 = 42.85$, $p < 0.001$). The influence of the presentation order is indeed only showed for primary knowledge content problems for which the enjoyment in performing the task ($M_{K1first} = 57.6 \pm 25.5$ vs. $M_{K2first} = 49.5 \pm 30.3$) ($estimate = -0.35$, $SE = 0.12$; $\chi^2 = 8.13$, $p = 0.004$) and the wish to find the correct answers ($M_{K1first} = 70.7 \pm 25.8$ vs. $M_{K2first} = 60.6 \pm 29.2$) ($estimate = -0.40$, $SE = 0.13$; $\chi^2 = 9.69$, $p = 0.002$) were higher when presented first.

7.2.3. The influence of added cognitive load

Overall, a high added cognitive load modality knowledge elicited lower performance ($M_{CL\ low} = 81.0 \pm 24.5$ vs. $M_{CL\ high} = 73.5 \pm 24.9$) ($estimate = -0.34$, $SE = 0.09$; $\chi^2 = 13.04$, $p < 0.001$), enjoyment in performing the task ($M_{CL\ low} = 55.0 \pm 27.1$ vs. $M_{CL\ high} = 43.4 \pm 29.5$) ($estimate = -0.46$, $SE = 0.11$; $\chi^2 = 16.20$, $p < 0.001$), wish to find the correct answers ($M_{CL\ low} = 68.9 \pm 26.4$ vs. $M_{CL\ high} = 57.0 \pm 30.2$) ($estimate = -0.42$, $SE = 0.12$; $\chi^2 = 12.25$, $p < 0.001$) and confidence in given responses ($M_{CL\ low} = 57.9 \pm 29.9$ vs. $M_{CL\ high} = 46.4 \pm 30.0$) ($estimate = -0.45$, $SE = 0.11$; $\chi^2 = 15.52$, $p < 0.001$). There was no interaction effect between the added cognitive load and the knowledge type ($ps > 0.48$).

Table 5

Results from linear mixed-effects models regarding the influence of the two knowledge types on the dependent variables in Experiment 5. Analysis were described with means (M), standard deviation (SD) and standard error of the estimate (SE).

	Primary knowledge		Secondary knowledge		Estimate	SE	χ^2	p
	M	SD	M	SD				
Performance	85.2	22.2	69.4	25.1	-0.63	0.05	164.86	<0.001
Enjoy answering questions	53.4	28.4	45.2	28.9	-0.28	0.04	56.15	<0.001
Want to find the correct answers	65.4	28.0	60.6	29.7	-0.16	0.03	21.35	<0.001
Confidence	56.7	30.1	47.7	30.3	-0.29	0.03	68.80	<0.001
Perceived cognitive load	50.2	22.4	57.0	22.5	0.30	0.04	54.24	<0.001
Speed (pb/min) (n = 179)	4.9	9.6	4.7	11.6	-0.03	0.07	0.15	0.70

7.2.4. Additional analyses: the ABC problems and the total subjective cognitive load

Presenting primary knowledge contents first decreased the overall perceived cognitive load ($M_{K1first} = 54.1 \pm 23.8$ vs. $M_{K2first} = 60.9 \pm 26.1$) ($F(1,208) = 4.30$, $p = 0.04$, $\eta_p^2 = 0.02$) but had no effect on responses to ABC syllogisms. The added cognitive load influenced the perceived cognitive load on the last ABC problems ($M_{CL\ low} = 46.3 \pm 26.7$ vs. $M_{CL\ high} = 39.4 \pm 25.9$) ($F(1,208) = 3.65$, $p = 0.05$, $\eta_p^2 = 0.02$): participants considered that ABC problems were less difficult and demanded in terms of working memory resources than syllogisms with reversed words. The added cognitive load influenced the overall cognitive load in an expected way ($M_{CL\ low} = 54.4 \pm 25.5$ vs. $M_{CL\ high} = 61.0 \pm 25.5$) ($F(1,208) = 4.69$, $p = 0.03$, $\eta_p^2 = 0.02$).

7.2.5. Discussion

Hypothesis 1: Experiment 5 expanded the range of validity of both types of knowledge; primary knowledge presentation had a positive influence on all the variables studied, even with unknown words. **Hypothesis 2:** again, we found that presenting primary knowledge first could have a general positive effect by increasing confidence in participants' responses and decreasing the perceived cognitive load. The fact that the presentation order influenced only primary knowledge contents on the variables related to emotional and cognitive investment may indicate that when secondary knowledge contents were presented first, they undermined participants' commitment to problems that should have been inherently motivating.

The results regarding the impact of the added cognitive load seemed to be consistent with the cognitive load theory: a high added cognitive load reduced the performance, commitment and confidence of the participants. However, there was no interaction between the added cognitive load and the knowledge type as expected in **Hypothesis 3a**. The explanation could be that the proposed problems were primarily secondary knowledge problems, and we only disguised them with words that evoked primary or secondary knowledge. It therefore seemed normal to regain the influence of cognitive load even on primary knowledge content problems. In addition, the words used were intended to minimize the influence of prior knowledge by describing non-existent things, which could also increase the need for cognitive resources to be processed. In order to get a synthetic overview of the results presented in these five experiments, we conducted a pooled analysis.

8. Pooled analyses and discussion

This analysis compiled data from the five studies presented in order to conclude about the influence of the knowledge types in solving logical problems on performance, enjoying answering questions, wanting to find the correct answers, confidence and perceived cognitive load. **Hypothesis 1:** in order to test the evolutionary approach of knowledge, primary knowledge should have a beneficial effect on all variables. **Hypothesis 2:** if primary knowledge was inherently motivating and secondary knowledge required cognitive resources and motivation, presenting primary knowledge first should encourage engagement of participants; conversely, introducing secondary knowledge first, as was

customary during the learning process, would undermine the motivation of participants. Hypothesis 3: given their cognitive resource-intensive characteristics, secondary knowledge was likely to be more affected by situations where the added cognitive load was high (i.e., [Hypothesis 3a](#): high added cognitive load modality or [Hypothesis 3b](#): conflict syllogisms).

The analyses processed the aggregated data using the same tests as previously used. The total number of participants was $n = 720$. The number of participants who did not take a break during experiments 1, 2, 3 and 5 was $n = 603$. The number of participants selected to analyze the problem type (conflict/non-conflict) influence was $n = 508$ (experiences 1 to 4).

8.1. The two knowledge types

For all five experiments, compared with secondary knowledge content, primary knowledge contents elicited higher performance, enjoyment in performing the task, wish to find the correct answers and confidence in given responses as well as a lower perceived cognitive load ([Table 6](#)).

The knowledge type had no effect on the speed at which syllogisms are solved, suggesting that differences in other variables were not due to the time spent analyzing problems. These results therefore validated [Hypothesis 1](#) about the positive influence of primary knowledge over secondary knowledge on all the variables of interest. As the evolutionary approach of knowledge pointed out, there may therefore be two types of knowledge with different characteristics: primary knowledge would be processed easily, with confidence and motivation, while secondary knowledge would require more cognitive resources to be processed with less confidence and motivation. These results were robust throughout our study whether the words are known or unknown ([Fig. 4](#)). In fact, the characteristics of both types of knowledge went beyond the familiar and unfamiliar, and primary knowledge did not appear to be characterized solely by the immediate environment.

8.2. Presentation order

Overall, participants enjoyed answering questions more when primary knowledge contents were presented first ($M_{K1first} = 58.2 \pm 26.8$ vs. $M_{K2first} = 52.9 \pm 28.2$) ($estimate = -0.19$, $SE = 0.06$; $\chi^2 = 9.83$, $p = 0.002$). Marginally, they also had more confidence in their responses when primary knowledge was presented first ($M_{K1first} = 55.8 \pm 28.1$ vs. $M_{K2first} = 52.7 \pm 29.9$) ($estimate = -0.10$, $SE = 0.06$; $\chi^2 = 2.85$, $p = 0.09$). As [Hypothesis 2](#) suggested, presenting primary knowledge first could therefore be an asset in motivating individuals to perform a secondary knowledge task.

The interaction between the knowledge type and the presentation order was significant for the performance ($\chi^2 = 5.35$, $p = 0.02$) and the enjoyment in performing the task ($\chi^2 = 73.61$, $p < 0.001$) ([Fig. 5](#)). Presenting primary knowledge first led to higher performance for secondary knowledge content problems only ($M_{K1first} = 59.2 \pm 32.6$ vs. $M_{K2first} = 54.7 \pm 30.2$) ($estimate = -0.14$, $SE = 0.05$; $\chi^2 = 6.43$, $p = 0.01$). This result, not observed for primary knowledge contents, could

show a training effect that favored secondary knowledge and not primary knowledge. In addition, presenting secondary knowledge first reduced the enjoyment in solving primary knowledge content problems ($M_{K1first} = 63.2 \pm 25.0$ vs. $M_{K2first} = 53.1 \pm 28.6$) ($estimate = -0.36$, $SE = 0.06$; $\chi^2 = 31.77$, $p < 0.001$) but not in solving secondary knowledge content problems. Secondary knowledge, when presented first, may therefore undermine participants even for content that should be inherently motivating, further arguing in favor of [Hypothesis 2](#).

8.3. The influence of added cognitive load on the two knowledge types

Overall, a high added cognitive load modality decreased performance ($M_{CL\ low} = 66.6 \pm 32.8$ vs. $M_{CL\ high} = 61.7 \pm 33.3$) ($estimate = -0.15$, $SE = 0.04$; $\chi^2 = 11.23$, $p < 0.01$) and confidence in given responses ($M_{CL\ low} = 57.3 \pm 28.7$ vs. $M_{CL\ high} = 51.2 \pm 29.1$) ($estimate = -0.20$, $SE = 0.06$; $\chi^2 = 11.67$, $p < 0.001$). [Hypothesis 3a](#): no interaction was observed between the added cognitive load and the knowledge type. Several explanations could be given. First, solving syllogisms required secondary knowledge, so even if their contents were primary knowledge, the task mostly involved dealing with secondary knowledge to which cognitive load theory applied. Second, several variables may minimize the impact of the added cognitive load such as the presentation order (which was an intra-group variable) or the involvement of unknown words that may require more resources to be processed as the means of perceived cognitive load would tend to show. However, in this study, the added cognitive load modalities allowed to obtain some interesting results when investigating its cross effect with the syllogism type.

8.4. The influence of the problem type (conflict/non-conflict) and the added cognitive load on the two knowledge types

Non-conflict syllogisms ($M = 75.9 \pm 25.8$) lead to higher performance than conflict syllogisms ($M = 43.0 \pm 34.1$) ($estimate = -0.95$, $SE = 0.03$; $\chi^2 = 1060.83$, $p < 0.001$). The interaction between the syllogism type and the added cognitive load was significant according to literature ($\chi^2 = 10.48$, $p = 0.001$): faced with conflict syllogisms, a high added cognitive load modality decreased performance ($M_{CL\ low} = 46.5 \pm 34.3$ vs. $M_{CL\ high} = 39.7 \pm 33.6$) ($estimate = -0.19$, $SE = 0.07$; $\chi^2 = 6.78$, $p = 0.009$), whereas faced with non-conflict syllogisms, the added cognitive load did not influence performance ($\chi^2 = 0.01$, $p = 0.91$) ([Fig. 6a](#)).

The interaction effect between the syllogism type and the knowledge type ($\chi^2 = 63.44$, $p < 0.001$) reflected a greater impact of the knowledge type on the performance in non-conflict syllogisms ($M_{K1} = 86.8 \pm 20.6$ vs. $M_{K2} = 65.0 \pm 25.8$) ($estimate = -0.84$, $SE = 0.04$; $\chi^2 = 381.41$, $p < 0.001$) than on the performance in conflict syllogisms ($M_{K1} = 46.0 \pm 34.7$ vs. $M_{K2} = 40.0 \pm 33.3$) ($estimate = -0.17$, $SE = 0.03$; $\chi^2 = 30.79$, $p < 0.001$) ([Fig. 6b](#)). This was surprising as we expected with [Hypothesis 3b](#) to find more impact of the knowledge type on conflict problems that were more demanding of cognitive resources. It emphasized that, even when using a simple content on a task using secondary knowledge (light manipulation), primary knowledge contents always promoted performance. The secondary knowledge contents seemed to create a feeling of

Table 6

Results from linear mixed-effects models regarding the influence of the two knowledge types on the dependent variables in pooled analyses. Analysis were described with means (M), standard deviation (SD) and standard error of the estimate (SE).

	Primary knowledge		Secondary knowledge		Estimate	SE	χ^2	p
	M	SD	M	SD				
Performance	71.3	33.2	56.9	31.4	-0.43	0.03	209.72	<0.001
Enjoy answering questions	58.1	27.4	52.9	27.7	-0.18	0.02	83.33	<0.001
Want to find the correct answers	66.6	25.5	63.8	26.7	-0.11	0.02	28.24	<0.001
Confidence	56.6	28.8	51.7	29.0	-0.17	0.02	73.47	<0.001
Perceived cognitive load	41.2	22.6	45.3	22.9	0.18	0.02	79.56	<0.001
Speed (pb/min) (n = 603)	5.5	10.9	5.0	10.9	0.05	0.04	1.30	0.25

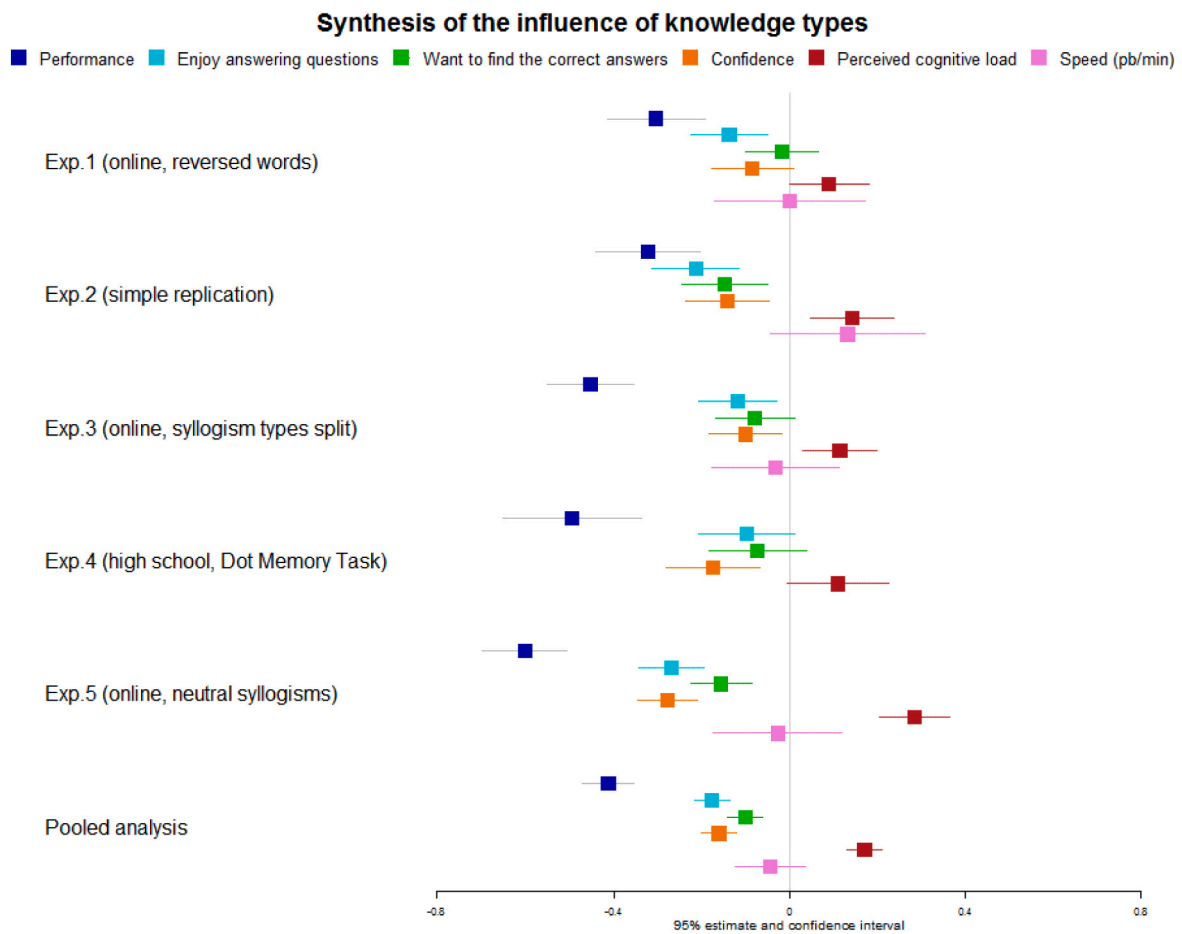
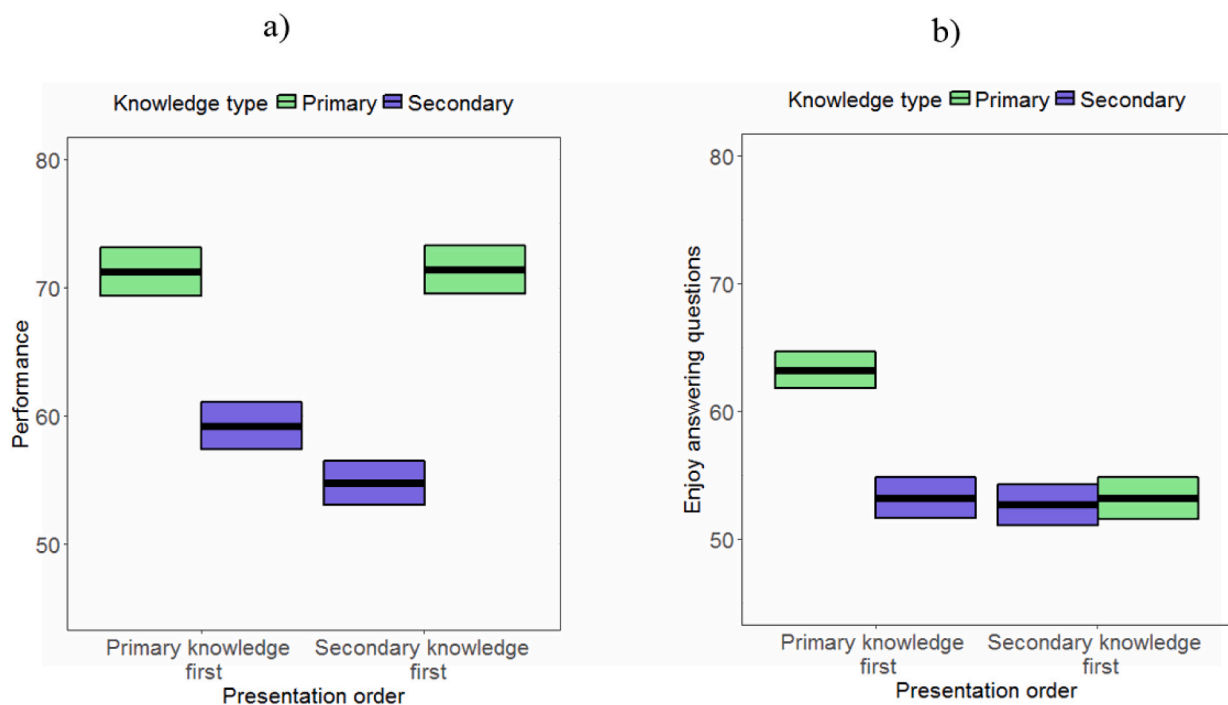
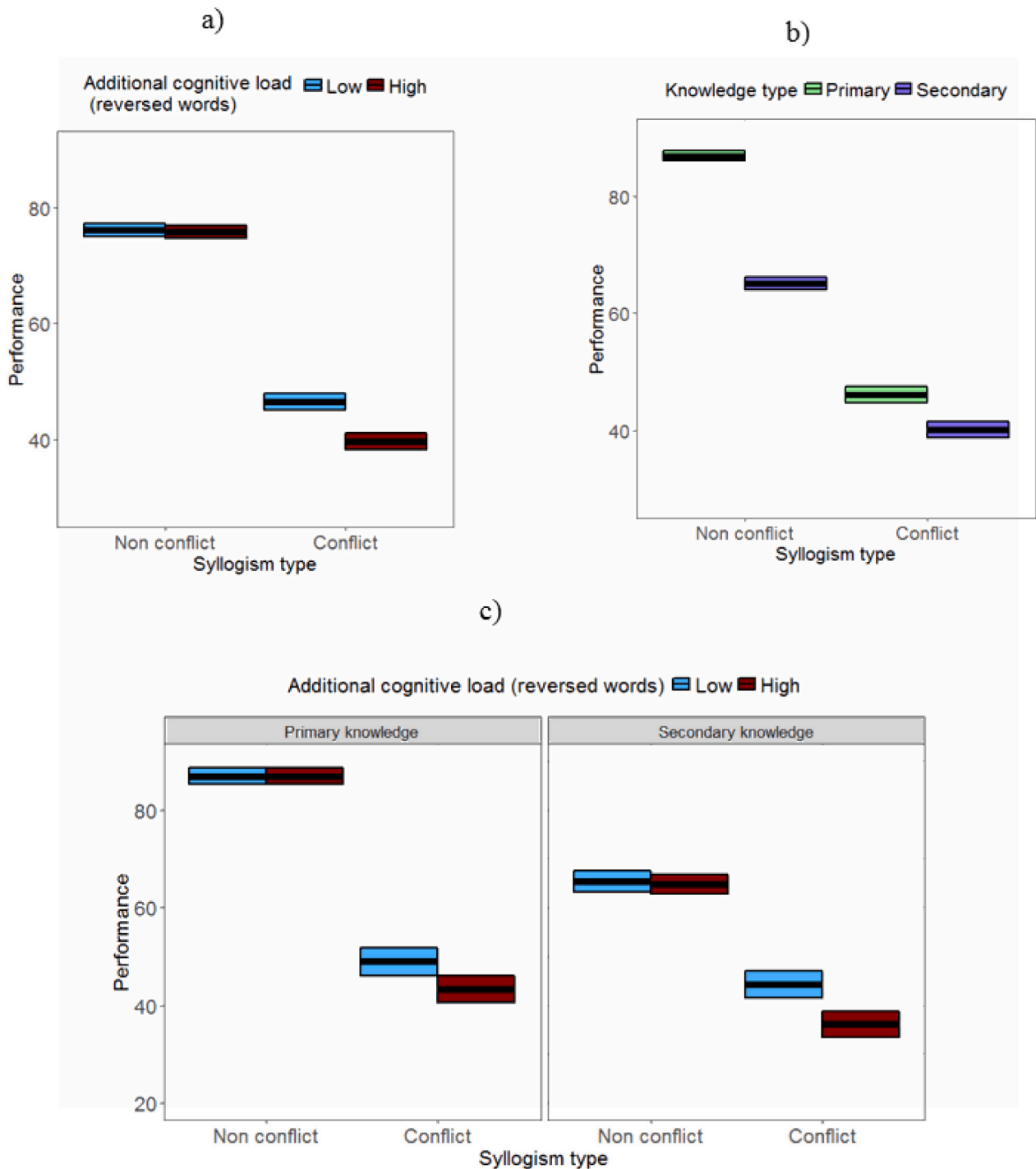


Fig. 4. Results from linear mixed-effects models (95% of the estimate and confidence interval) regarding the influence of the two knowledge types on the dependent variables in each experiment and in the pooled analysis (the reference modality was “primary knowledge”).



Figs. 5. Pooled analyses. Interactions between the presentation order and the knowledge types on a) performance and b) enjoy answering questions (boxplots represented the mean and 95% of the confidence interval).



Figs. 6. Pooled analyses (from experiments 1 to 4). Interactions between the syllogism type and a) the added cognitive load, b) the knowledge type and c) the added cognitive load and the knowledge type on participants' performance (boxplots represented the mean and 95% of the confidence interval).

conflict/cognitive load that persisted even for non-conflict problems. This sense of conflict may therefore be linked to the nature of secondary knowledge that could lead participants to mistrust their first answers and seek to produce another ones. Non-conflict syllogisms lead to higher performance in both primary ($M_{\text{non-conflict}} = 86.8 \pm 20.6$ vs. $M_{\text{conflict}} = 46.0 \pm 34.7$) ($\text{estimate} = -1.08$, $\text{SE} = 0.07$; $\chi^2 = 626.41$, $p < 0.001$) and secondary knowledge ($M_{\text{non-conflict}} = 65.0 \pm 25.8$ vs. $M_{\text{conflict}} = 40.0 \pm 33.3$) ($\text{estimate} = -0.77$, $\text{SE} = 0.04$; $\chi^2 = 302.70$, $p < 0.001$).

The interaction between the added cognitive load and the syllogism type was marginally significant for primary knowledge contents ($F(1,504) = 2.95$, $p = 0.09$) but significant for secondary knowledge

contents ($F(1,504) = 6.81$, $p = 0.009$) (Fig. 6c). Regarding secondary knowledge content problems, a high added cognitive load modality decreased the performance in conflict problems ($M_{\text{CL low}} = 44.2 \pm 33.9$ vs. $M_{\text{CL high}} = 36.1 \pm 32.3$) ($F(1,506) = 8.96$, $p = 0.003$, $\eta_p^2 = 0.01$) but did not influence the performance in non-conflict problems ($M_{\text{CL low}} = 65.3 \pm 26.7$ vs. $M_{\text{CL high}} = 64.7 \pm 25.0$) ($F(1,506) = 0.09$, $p = 0.76$, $\eta_p^2 < 0.001$). According to Hypothesis 1 and 3, this result might highlight that the processing of primary knowledge did not require specific cognitive resources. Indeed, the interaction between the added cognitive load and the syllogism type was clearly significant only for secondary knowledge contents which, by definition, required cognitive resources to be

processed. The marginal significance of the interaction for primary knowledge might come from the fact that this knowledge was only a content applied on a problem related to secondary knowledge (thus requiring cognitive resources). Even so, the results emphasized that a simple content made it easier to deal with non-motivating problems.

8.5. Additional analyses: the ABC problems and the total subjective cognitive load

Regarding the responses to the last ABC problems, when primary knowledge were presented first, participants got higher performance ($M_{K1\text{first}} = 55.2 \pm 24.6$ vs. $M_{K2\text{first}} = 52.9 \pm 24.9$) ($F(1,716) = 7.34$, $p = 0.006$, $\eta_p^2 = 0.002$), enjoyed answering questions in a higher way ($M_{K1\text{first}} = 55.8 \pm 27.9$ vs. $M_{K2\text{first}} = 51.6 \pm 29.4$) ($F(1,716) = 17.53$, $p < 0.001$, $\eta_p^2 = 0.005$) and felt more confident in their given responses ($M_{K1\text{first}} = 57.0 \pm 29.6$ vs. $M_{K2\text{first}} = 54.1 \pm 31.7$) ($F(1,716) = 7.60$, $p = 0.006$, $\eta_p^2 = 0.002$). Participants also experienced less cognitive load overall when primary knowledge were presented first ($M_{K1\text{first}} = 47.4 \pm 22.0$ vs. $M_{K2\text{first}} = 50.0 \pm 22.4$) ($F(1,716) = 11.75$, $p < 0.001$, $\eta_p^2 = 0.003$). **Hypothesis 2:** the presentation order of the two types of knowledge would therefore be an interesting element to take into account when considering tasks that required involvement, such as learning tasks, particularly since it could facilitate transfer processes and engagement throughout these tasks.

The added cognitive load influenced the perceived cognitive load during the last ABC problems ($M_{CL\text{ low}} = 46.7 \pm 26.1$ vs. $M_{CL\text{ high}} = 42.5 \pm 23.5$) ($F(1,716) = 23.51$, $p < 0.001$, $\eta_p^2 = 0.007$) and the overall perceived cognitive load ($M_{CL\text{ low}} = 47.5 \pm 21.9$ vs. $M_{CL\text{ high}} = 50.0 \pm 22.5$) ($F(1,716) = 11.14$, $p < 0.001$, $\eta_p^2 = 0.003$). That is, participants felt that ABC problems were less demanding on cognitive resources than the syllogisms of the main task when the added cognitive load modality was high. This was confirmed by the second result: participants generally felt more cognitive load on the whole process when the added cognitive load modality was high.

9. General discussion

This empirical study proposed to challenge the evolutionary approach of knowledge that defined primary (knowledge emerged early in evolutionary time, processed effortlessly, quickly and intrinsically motivating) and secondary knowledge (knowledge emerged more recently in evolutionary time, requiring cognitive resources for processing, time and effort to be learned, and with which we have little motivation to deal). As those two knowledge types were hardly directly comparable, we tested their characteristics by using the knowledge type as logical problem contents. Furthermore, since secondary knowledge was built on the basis of primary knowledge, it would be interesting to use the characteristics of primary knowledge to encourage individuals to invest in a task that was not motivating. Through five experiments, we varied (i) the content of syllogisms (primary or secondary knowledge), (ii) the order in which this knowledge was presented, (iii) the added extrinsic cognitive load, and (iv) the syllogism type (conflict or non-conflict). People's syllogistic reasoning in evolved domains (folk biology) would be more accurate, less demanding of working memory resources, and more motivationally engaging than the same forms of reasoning applied to evolutionarily novel domains, such as mathematics and formal grammar. The results showed that, compared to secondary knowledge, whether the content was familiar or not, primary knowledge had a positive influence on performance, emotional and cognitive commitment to the task and confidence in responses. It also reduced the perceived cognitive load. Second, presenting primary knowledge first may encourage participants to be motivated throughout the task, while presenting secondary knowledge first may undermine their motivation. Finally, it seemed that secondary knowledge led to a feeling of conflict and to increase cognitive load (even when the problem type should not lead to conflict) related to its nature that consumed cognitive resources.

9.1. Primary knowledge would promote performance and motivation

Validating **Hypothesis 1**, our study showed in a robust way that primary knowledge, even as a secondary knowledge problem contents (syllogism), promoted participants performance, engagement and confidence. It also reduced the perceived cognitive load, which is consistent with the evolutionary approach to knowledge (Geary & Berch, 2016; Sweller, 2016). Individuals may be equipped early to reason easily about this type of knowledge. Like the deontic rules (Cosmides & Tooby, 2004) which could be considered as primary knowledge, the latter were free from concretization or familiarity. Individuals were equally effective at thinking about unknown and known foods (Lespiau & Tricot, 2018), just as they reasoned about both an invented social rule and a familiar one (Gigerenzer & Hug, 1992). Primary knowledge may therefore concern unfamiliar or unknown content, contrary to what Roussel et al. (2017) suggested. To use food as an example, we evolved to control our intensely fluctuating environment to achieve the best nutritional quality (Geary & Berch, 2016; Kaplan, Hill, Lancaster, & Hurtado, 2000).

Moreover, the failure to observe an interaction effect between the added cognitive load and the knowledge type (especially in Experiment 5) might illustrate the existence of a continuum between the knowledge types with, at one extreme, primary knowledge met in our direct environment and, at the other extreme, secondary knowledge; the intermediate step would be the primary knowledge that is not part of our direct environment (Roussel et al., 2017). Experiment 5 involved knowledge that did not exist in the participants' direct environment (unknown words) and therefore more distant on the continuum at the scale of evolution. Added to this was the fact that knowledge types were just the contents of problems whose rule to extract was secondary knowledge. It therefore seemed appropriate that the cognitive load should apply to both content types. New avenues of research may focus on whether the characteristics of primary knowledge fade as it move away from the extreme and gradually take on the characteristics of secondary knowledge.

9.2. Presenting primary knowledge first was beneficial

Validating **Hypothesis 2**, the results showed that it was possible to build on primary knowledge to encourage participant investment (Paas & Ayres, 2014). Presenting primary knowledge content first promoted the enjoyment in performing the task and performance for secondary knowledge content. Conversely, presenting secondary knowledge content first undermined participants' motivation even for problems whose content should be inherently motivating (primary knowledge). On the final ABC task that could act as a transfer task, presenting primary knowledge content first and then secondary knowledge content fostered performance, emotional investment and confidence in the final answers. This order of presentation also reduced the perceived cognitive load on the whole task. It would therefore be an interesting presentation modality to avoid the demotivating effect of secondary knowledge and encourage transfer.

The transfer task proposed in the present materials made it possible to investigate whether primary knowledge could promote the learning of secondary knowledge but superficially. Indeed, the objective presented to the participants was not to learn the rules of logic but only to solve the problems. New studies would be able to use these first results regarding the presentation order and test them with a clearly identified learning task. Faced with new knowledge to be acquired, presenting primary knowledge first rather than secondary knowledge directly could be an asset in pedagogical practices. The issues of potential overlap between primary and secondary knowledge is important and might be applicable to aspects of children's early learning (Toub et al., 2016).

9.3. Secondary knowledge would lead to a feeling of conflict and consume cognitive resources

This study highlighted findings that were contrary to our Hypothesis 3. Indeed, while primary knowledge promoted performance in conflict problems comparing with secondary knowledge, this effect was much more pronounced for non-conflict problems. We expected to find no performance differences for non-conflict syllogisms. This result could be partially explained by the fact that primary and secondary knowledge were simply contents given the structure of syllogisms themselves were secondary knowledge. However, primary knowledge contents systematically promoted performance, while secondary knowledge contents led to a feeling of conflict that could lead participants to mistrust their first answers and burdened cognitive resources (even and in a higher extent for non-conflict problems). This conflict might be related to the nature of secondary knowledge. It could be interpreted into discouragement behaviour specific to secondary knowledge and the perception that we are not capable of solving the problem. In addition, the interaction between the syllogism type and the added cognitive load modality was only significant for secondary knowledge content validating the fact that this knowledge required cognitive resources. These results did not allow a strict conclusion to be drawn about the influence of the two mechanisms on the knowledge types. But it would appear that secondary knowledge, by its nature (demanding in cognitive resources and leading participants to mistrust their first answers), directly implies Type 2 mechanisms. However, secondary knowledge would saturate the working memory too much for Type 2 mechanisms to generate the response (low overall performance for secondary knowledge). In addition, the results of Experiment 3 did not show any influence of the syllogism type on the perceived cognitive load when it came to secondary knowledge, showing that the perceived cognitive load was already strong.

Conversely, primary knowledge, even used as a simple content, even with unknown words, left enough resources to generate the correct answer. It remained to be seen whether this correct answer was related to Type 1 or Type 2 mechanisms. Indeed, new conceptions of dual-process emphasized that logical judgments could be made intuitively, unconsciously and effortlessly (Bago & De Neys, 2017). New experiments could focus on using these new approaches to test the involvement of mechanisms in processing both types of knowledge.

This paper proposed to test the characteristics of the two types of knowledge defined by the evolutionary approach (Geary & Berch, 2016)

through the use of logical problem content. Compared with secondary knowledge content, using primary knowledge content in syllogisms influenced positively performance, emotional and cognitive engagement and confidence and decreased the perceived cognitive load. Thus, using primary knowledge first promoted the acquisition of secondary knowledge and maintained motivation throughout the task. In addition, secondary knowledge seemed to create a sense of conflict that consumed cognitive resources, hindering the reasoning process. The evolutionary psychology perspective on knowledge types had yet to be tested, but it allowed to rethink theories such as the cognitive load one (Sweller, 2008). What individuals already know (primary knowledge) should not be overlooked on the pretext that they are already acquired. On the contrary, relying on this knowledge would seem to be an asset in the struggle to motivate individuals in tasks that do not initially inspire them.

Ethical principles

This study was conducted in accordance with the ethical standards of the institutional and national guidelines and with the Declaration of Helsinki (2008). Informed consent was obtained from all individual participants included in the study.

Context paragraph

This paper tests the characteristics of primary knowledge (that emerged early in evolutionary time, processed effortlessly, quickly, and intrinsically motivating) and secondary knowledge (that emerged recently in evolutionary time, which requires cognitive resources, time, and is demotivating) defined by the evolutionary approach. As secondary knowledge is built on the basis of primary knowledge, we also want to test whether primary knowledge can encourage investment in a task that includes low motivation secondary knowledge and promote its integration. To do this, we used the paradigm of research on reasoning, particularly syllogisms that may induce belief bias (conflict ones). This allowed us to link the two approaches and investigate what mechanisms were involved in dealing with both types of knowledge.

Declaration of competing interest

The authors declare that there is no conflict of interest.

Appendix A

A.1. Syllogisms used in experiments from 1 to 4 (material presented in French to participants and translated for the appendix)

Knowledge type	Logical status	Conflict syllogisms	Non-conflict syllogisms
Primary knowledge information related contents	Invalid	All human beings have two hands, Men have two hands, Therefore men are human beings. (believable)	All drinkable liquids are bottled liquids, Household alcohol is a bottled liquid, Therefore household alcohol is a drinkable liquid. (unbelievable)
		All cakes can be eaten, Chocolate cookies can be eaten, Therefore chocolate cookies are cakes. (believable)	All pregnant women have round bellies, Beer drinkers have round bellies, Therefore beer drinkers are pregnant women. (unbelievable)
	Valid	All dairy products can be drunk, Cheese is a dairy product, Therefore cheese can be drunk. (unbelievable)	All mammals can walk, Cats are mammals, Therefore cats can walk. (believable)
		All felines are wild, Domestic cats are felines, Therefore domestic cats are wild. (unbelievable)	All pizzas are high in fat, The 5 cheeses is a pizza, Therefore the 5 chesses is high in fat. (believable)
		All bottles liquids are drinkable,	

(continued on next page)

(continued)

Knowledge type	Logical status	Conflict syllogisms	Non-conflict syllogisms
Secondary knowledge information related contents	Invalid	Household alcohol is a bottled liquid, Therefore household alcohol is a drinkable liquid. (unbelievable)	All squares are figures with four equal sides, A lozenge is a figure with four equal sides, Therefore a lozenge is a square. (unbelievable)
		All French adjectives in the feminine end in -e, “Jolie” ends in -e, Therefore “jolie” is a French adjective in the feminine. (believable)	
	Valid	All circles are round, The base of a cone is round, Therefore the base of a cone is a circle. (believable)	All the French verbs of the first group end in -er, “Aller” ends in -er, Therefore “aller” is a French verb of the first group. (unbelievable)
		All prime numbers are odd numbers, 2 is a prime number, Therefore 2 is an odd number. (unbelievable)	All French common names end in -s in the plural, “Chien” is a common French name, Therefore “chien” ends in -s in the plural. (believable)
		All French plural adjectives end in -s, “Joyeux” is a French plural adjective, Therefore “joyeux” ends in -s. (unbelievable)	All isosceles triangles have two sides of the same length, Equilateral triangles are isosceles, Therefore the equilateral triangles have two sides of the same length. (believable)
		All figures with four equal sides are squares, A lozenge has four equal sides, Therefore a lozenge is a square. (unbelievable)	

A.2. Syllogisms used in Experiment 5 (material presented in French to participants and translated for the appendix)

Knowledge type	Valid syllogisms	Invalid syllogisms
Primary knowledge information related contents	All jonquab products can be drunk, Raw houmi is a jonquab product, Therefore raw houmi can be drunk.	All alkékenges are eaten in sauce, Red uglis are eaten in sauce, Therefore red uglis are alkékenges.
	All ronvacs are wild and herbivorous, Yellow horned cachuls are ronvacs, Therefore yellow horned cachuls are wild and herbivorous.	All dangerous Hutar females have dark blue bellies, Toami has a dark blue belly, Therefore Toami is a dangerous Hutar female.
	All bottled mugichas are drinkable, But the robotom is not drinkable, Therefore the robotom is not a bottled mugicha.	All loutas are sweet and juicy, The white rouli is not a louta, Therefore the white rouli is not sweet and juicy.
Secondary knowledge information related contents	All oncilles have three hairy legs, But grogs are not have three hairy legs, Therefore grogs are not oncilles.	All individuals from the Knol tribe can walk, The fouards are not individuals from the Knol tribe, Therefore the fouards cannot walk.
	All Sendamin adjectives end in -an in the plural, “Lephae” is a Sendamin adjective, Therefore “lephae” ends in -in in the plural.	All Sendamin gerund verbs end in -ni, “Norauni” ends in -ni, Therefore “norauni” is a Sendamin gerund verb.
	All Foster equations are the type $x = \sqrt{(3b - 2ac)}$, Jyrog formula is a Foster equation, Therefore Jyrog formula is the type $x = \sqrt{(3b - 2ac)}$.	All Barry volumes are calculated by $\sum(R_x - 1 / 5\pi)$, The volume of a disphenoid is calculated by $\sum(R_x - 1 / 5\pi)$, Therefore the volume of a disphenoid is a Barry volume.
	All Quenty feminine adjectives end in -mma, “Galahm” does not end in -mma, Therefore “galahm” is not a Quenty feminine adjective.	All Sendamin common names end in -li in the plural, “Alda” is not a Sendamin common name, Therefore “alda” does not end in -li in the plural.
	All Hat polyhedral have $7(n - 1)$ half spaces, The cubocaoid does not have $7(n - 1)$ half spaces, Therefore the cubocaoid is not a Hat polyhedron.	All areas of a Hastor figure are calculated by $3(x + 2\pi)$, The area of a volgooid is not an area of a Hastor figure, Therefore the area of a volgooid is not calculated by $3(x + 2\pi)$.

References

- Bago, B., & De Neys, W. (2017). Fast logic?: Examining the time course assumption of dual process theory. *Cognition*, 158, 90–109. <https://doi.org/10.1016/j.cognition.2016.10.014>
- Beck, F., & Richard, J.-B. (2010). *Les comportements de santé des jeunes*. Inpes. <http://inpes.santepubliquefrance.fr/Barometres/barometre-sante-2010/comportement-sante-jeunes/pdf/Alimentation-12-30-ans.pdf>
- Beller, S. (2010). Deontic reasoning reviewed: Psychological questions, empirical findings, and current theories. *Cognitive Processing*, 11(2), 123–132. <https://doi.org/10.1007/s10339-009-0265-z>
- Bethell-Fox, C. E., & Shepard, R. N. (1988). Mental rotation: Effects of stimulus complexity and familiarity. *Journal of Experimental Psychology: Human Perception and Performance*, 14(1), 12–23. <https://doi.org/10.1037/0096-1523.14.1.12>
- Binkley, M., Erstad, O., Herman, J., Raizen, S., Ripley, M., Miller-Ricci, M., & Rumble, M. (2012). Defining twenty-first century skills. In P. Griffin, B. McGaw, & E. Care (Eds.), *Assessment and teaching of 21st century skills* (pp. 17–66). Springer.
- Braver, T. S., Krug, M. K., Chiew, K. S., Kool, W., Westbrook, J. A., Clement, N. J., Adcock, R. A., Barch, D. M., Botvinick, M. M., Carver, C. S., Cools, R., Custers, R., Dickinson, A., Sweck, C. S., Fishbach, A., Gollwitzer, P. M., Hess, T. M., Isaacowitz, D. M., Mather, M., ... Somerville, L. H. (2014). Mechanisms of motivation–cognition interaction: Challenges and opportunities. *Cognitive, Affective, & Behavioral Neuroscience*, 14(2), 443–472. <https://doi.org/10.3758/s13415-014-0300-0>

- Castles, A., Rastle, K., & Nation, K. (2018). Ending the reading wars: Reading acquisition from novice to expert. *Psychological Science in the Public Interest*, 19(1), 5–51. <https://doi.org/10.1177/1529100618772271>
- Chu, F. W., vanMarle, K., & Geary, D. C. (2015). Early numerical foundations of young children's mathematical development. *Journal of Experimental Child Psychology*, 132, 205–212. <https://doi.org/10.1016/j.jecp.2015.01.006>
- Cosmides, L., Barrett, H. C., & Tooby, J. (2010). Adaptive specializations, social exchange, and the evolution of human intelligence. *Proceedings of the National Academy of Sciences*, 107, 9007–9014. <https://doi.org/10.1073/pnas.0914623107>
- Cosmides, L., & Tooby, J. (2004). Knowing thyself: The evolutionary psychology of moral reasoning and moral sentiments. *The Ruffin Series of the Society for Business Ethics*, 4, 93–128. <https://doi.org/10.5840/ruffinx200447>
- Cosnefroy, O., Nurra, C., & Dessus, P. (2016). Analyse dynamique de la motivation des élèves en début de scolarité obligatoire en fonction de la nature de leurs interactions avec l'enseignant. *Éducation et Formations*, 90, 29–51. doi: hal-01306393.
- De Neys, W. (2006). Dual processing in reasoning: Two systems but one reasoner. *Psychological Science*, 17(5), 428–433. <https://doi.org/10.1111/j.1467-9280.2006.01723.x>
- De Neys, W. (2012). Bias and conflict: A case for logical intuitions. *Perspectives on Psychological Science*, 7(1), 28–38. <https://doi.org/10.1177/1745691611429354>
- De Neys, W. (2021). On dual and single-process models of thinking. *Perspectives on Psychological Science*, 16(6), 1412–1427. <https://doi.org/10.1177/1745691620964172>
- 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. <https://doi.org/10.1016/j.tics.2013.02.001>
- De Neys, W., Cromheeke, S., & Osman, M. (2011). Biased but in doubt: Conflict and decision confidence. *PLoS one*, 6(1). <https://doi.org/10.1371/journal.pone.0015954>
- De Neys, W., & Feremans, V. (2013). Development of heuristic bias detection in elementary school. *Developmental Psychology*, 49(2), 258. <https://doi.org/10.1037/a0028320>
- De Neys, W., & Franssens, S. (2009). Belief inhibition during thinking: Not always winning but at least taking part. *Cognition*, 113(1), 45–61. <https://doi.org/10.1016/j.cognition.2009.07.009>
- De Neys, W., & Glumicic, T. (2008). Conflict monitoring in dual process theories of thinking. *Cognition*, 106(3), 1248–1299. <https://doi.org/10.1016/j.cognition.2007.06.002>
- De Neys, W., Moyens, E., & Vansteenwegen, D. (2010). Feeling we're biased: Autonomic arousal and reasoning conflict. *Cognitive, Affective, & Behavioral Neuroscience*, 10(2), 208–216. <https://doi.org/10.3758/CABN.10.2.208>
- De Neys, W., Vartanian, O., & Goel, V. (2008). Smarter than we think: When our brains detect that we are biased. *Psychological Science*, 19(5), 483–489. <https://doi.org/10.1111/j.1467-9280.2008.02113.x>
- Dominowski, R. L. (1995). Content effects in Wason's selection task. In S. E. Newstead, & J. S. B. Evans (Eds.), *Perspectives on thinking and reasoning: Essays in honour of Peter Wason* (pp. 41–65). Lawrence Erlbaum.
- Evans, J. S. B. (2003). In two minds: Dual-process accounts of reasoning. *Trends in Cognitive Sciences*, 7(10), 454–459. <https://doi.org/10.1016/j.tics.2003.08.012>
- Evans, J. S. B. (2016). Reasoning, biases and dual processes: The lasting impact of Wason (1960). *The Quarterly Journal of Experimental Psychology*, 69(10), 2076–2092. <https://doi.org/10.1080/17470218.2014.914547>
- Evans, J. S. B., & Frankish, K. E. (2009). *In two minds: Dual processes and beyond*. Oxford University Press.
- Fiddick, L., Cosmides, L., & Tooby, J. (2000). No interpretation without representation: The role of domain-specific representations and inferences in the wason selection task. *Cognition*, 77(1), 1–79. [https://doi.org/10.1016/S0010-0277\(00\)00085-8](https://doi.org/10.1016/S0010-0277(00)00085-8)
- Geary, D. C. (1995). Reflections of evolution and culture in children's cognition: Implications for mathematical development and instruction. *American Psychologist*, 50(1), 24–37. <https://doi.org/10.1037/0003-066X.50.1.24>
- Geary, D. C. (2007). Educating the evolved mind: Conceptual foundations for an evolutionary educational psychology. In J. S. Carlson, & J. R. Levin (Eds.), *Educating the evolved mind: Conceptual foundations for an evolutionary educational psychology* (pp. 1–99). Information Age.
- Geary, D. C. (2008). An evolutionarily informed education science. *Educational Psychologist*, 43(4), 179–195. <https://doi.org/10.1080/00461520802392133>
- Geary, D. C. (2012). Application of evolutionary psychology to academic learning. In S. C. Roberts (Ed.), *Applied evolutionary psychology* (pp. 78–92). Oxford University Press.
- Geary, D. C., & Berch, D. (2015). Evolutionary approaches to understanding children's academic achievement. In R. A. Scott, & S. M. Kosslyn (Eds.), *Emerging trends in the social and behavioral sciences* (pp. 1–10). Wiley. <https://doi.org/10.1002/9781118900772.etrds0123>
- Geary, D. C., & Berch, D. (2016). Evolution and children's cognitive and academic development. In D. C. Geary, & D. Berch (Eds.), *Evolutionary perspectives on child development and education* (pp. 217–249). Springer International.
- Geary, D. C., & Bjorklund, D. F. (2000). Evolutionary developmental psychology. *Child Development*, 71(1), 57–65. <https://doi.org/10.1111/1467-8624.00118>
- Gelman, R. (1990). First principles organize attention to and learning about relevant data: Number and the animate-inanimate distinction as examples. *Cognitive Science*, 14(1), 79–106. https://doi.org/10.1207/s15516709cog1401_5
- Génolini, J.-P., Ehlinger, V., Escalon, H., & Godeau, E. (2016). La santé des collégiens en France/2014 - Habitudes alimentaires, activité physique et sédentarité. In *Données françaises de l'enquête internationale Health Behaviour in School-aged Children (HBSC)*. France: Santé publique.
- Gigerenzer, G., & Hug, K. (1992). Domain-specific reasoning: Social contracts, cheating, and perspective change. *Cognition*, 43(2), 127–171. [https://doi.org/10.1016/0010-0277\(92\)90060-U](https://doi.org/10.1016/0010-0277(92)90060-U)
- Glenberg, A. M., Goldberg, A. B., & Zhu, X. (2011). Improving early reading comprehension using embodied CAI. *Instructional Science*, 39(1), 27–39. <https://doi.org/10.1007/s11251-009-9096-7>
- Griggs, R. A., & Cox, J. R. (1982). The elusive thematic-materials effect in Wason's selection task. *British Journal of Psychology*, 73(3), 407–420. <https://doi.org/10.1111/j.2044-8295.1982.tb01823.x>
- Guichemmerre, C. (2011). *Enquête vie de campus*. Université de Bordeaux. http://www.cue-aquitaine.fr/docs/poleetudes/conditions_vie/tbdl.pdf
- Handley, S. J., & Trippas, D. (2015). Chapter Two-Dual processes and the interplay between knowledge and structure: a new parallel processing model. In B. Ross (Ed.), *The psychology of learning and motivation* (pp. 33–58). <https://doi.org/10.1016/bs.plm.2014.09.002>
- Johnson, E. D., Tubau, E., & De Neys, W. (2016). The doubting System1: Evidence for automatic substitution sensitivity. *Acta Psychologica*, 164, 56–64. <https://doi.org/10.1016/j.actpsy.2015.12.008>
- Kahneman, D., & Frederick, S. (2005). A model of heuristic judgment. In K. J. Holyoak, & R. G. Morrison (Eds.), *The Cambridge handbook of thinking and reasoning* (pp. 267–293). Cambridge University Press.
- Kanwisher, N., McDermott, J., & Chun, M. M. (1997). The fusiform face area: a module in human extrastriate cortex specialized for face perception. *Journal of Neuroscience*, 17(11), 4302–4311. doi: 0270-6474/97/174302-10\$05.00/0.
- Kaplan, H., Hill, K., Lancaster, J., & Hurtado, A. M. (2000). A theory of human life history evolution: Diet, intelligence, and longevity. *Evolutionary Anthropology: Issues, News, and Reviews*, 9(4), 156–185. [https://doi.org/10.1002/1520-6505\(2000\)9:4<156::AID-EVAN5>3.0.CO;2-7](https://doi.org/10.1002/1520-6505(2000)9:4<156::AID-EVAN5>3.0.CO;2-7)
- Khemlani, S., & Johnson-Laird, P. N. (2012). Theories of the syllogism: A meta-analysis. *Psychological Bulletin*, 138(3), 427–457. <https://doi.org/10.1037/a0026841>
- Kirschner, P., Paas, F., & Kirschner, P. A. (2011). Task complexity as a driver for collaborative learning efficiency: The collective working-memory effect. *Applied Cognitive Psychology*, 25(4), 615–624. <https://doi.org/10.1002/acp.1730>
- Léon, C., du Roscoat, E., Ehlinger, V., & Godeau, E. (2016). La santé des collégiens en France/2014 - Relations familiales et relations avec les pairs. In *Données françaises de l'enquête internationale Health Behaviour in School-aged Children (HBSC)*. France: Santé publique.
- Lespiau, F., & Tricot, A. (2018). Primary knowledge enhances performance and motivation in reasoning. *Learning and Instruction*, 56, 10–19. <https://doi.org/10.1016/j.learninstruc.2018.02.007>
- Lespiau, F., & Tricot, A. (2019). Using primary knowledge: An efficient way to motivate students and promote the learning of formal reasoning. *Educational Psychology Review*, 31, 915–938. <https://doi.org/10.1007/s10648-019-09482-4>
- Mandelbaum, E. (2013). Numerical architecture. *Topics in cognitive. Science*, 5(2), 367–386. <https://doi.org/10.1111/tops.12014>
- 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. <https://doi.org/10.1111/j.1467-8624.2010.01526.x>
- Mazzocco, M. M., Feigenson, L., & Halberda, J. (2011). Preschoolers' precision of the approximate number system predicts later school mathematics performance. *PLoS one*, 6(9), Article e23749.
- Miyake, A., Friedman, N. P., Rettinger, D. A., Shah, P., & Hegarty, M. (2001). How are visuospatial working memory, executive functioning, and spatial abilities related? A latent-variable analysis. *Journal of Experimental Psychology: General*, 130(4), 621–640. <https://doi.org/10.1037/0096-3445.130.4.621>
- Morsanyi, K., & Handley, S. J. (2008). How smart do you need to be to get it wrong? The role of cognitive capacity in the development of heuristic-based judgment. *Journal of Experimental Child Psychology*, 99(1), 18–36. <https://doi.org/10.1016/j.jecp.2007.08.003>
- Paas, F., & Ayres, P. (2014). Cognitive load theory: A broader view on the role of memory in learning and education. *Educational Psychology Review*, 26(2), 191–195. <https://doi.org/10.1007/s10648-014-9263-5>
- Paas, F., & Sweller, J. (2012). An evolutionary upgrade of cognitive load theory: Using the human motor system and collaboration to support the learning of complex cognitive tasks. *Educational Psychology Review*, 24(1), 27–45. <https://doi.org/10.1007/s10648-011-9179-2>
- Pacoricono Alfaro, D. L., Ehlinger, V., Sentenac, M., & Godeau, E. (2016). La santé des collégiens en France/2014 - Vécu scolaire. In *Données françaises de l'enquête internationale Health Behaviour in School-aged Children (HBSC)*. France: Santé publique.
- Ping, R., & Goldin-Meadow, S. (2010). Gesturing saves cognitive resources when talking about nonpresent objects. *Cognitive Science*, 34(4), 602–619. <https://doi.org/10.1111/j.1551-6709.2010.01102.x>
- Price, C. J. (1998). The functional anatomy of word comprehension and production. *Trends in Cognitive Sciences*, 2(8), 281–288. [https://doi.org/10.1016/S1364-6613\(98\)01201-7](https://doi.org/10.1016/S1364-6613(98)01201-7)
- Roussel, S., Jouliat, D., Tricot, A., & Sweller, J. (2017). Learning subject content through a foreign language should not ignore human cognitive architecture: A cognitive load theory approach. *Learning and Instruction*, 52, 69–79. <https://doi.org/10.1016/j.learninstruc.2017.04.007>
- Scholl, B. J., & Leslie, A. M. (1999). Modularity, development and 'theory of mind'. *Mind & Language*, 14(1), 131–153. <https://doi.org/10.1111/1468-0017.00106>
- Stanovich, K. E., & West, R. F. (2000). Individual differences in reasoning: Implications for the rationality debate? *Behavioral and Brain Sciences*, 23(05), 701–717.
- Stanovich, K. E., West, R. F., & Toplak, M. E. (2011). The complexity of developmental predictions from dual process models. *Developmental Review*, 31(2), 103–118. <https://doi.org/10.1016/j.dr.2011.07.003>

- Sweller, J. (2008). Instructional implications of David C. Geary's evolutionary educational psychology. *Educational Psychologist*, 43(4), 214–216. <https://doi.org/10.1080/00461520802392208>
- Sweller, J. (2015). In academe, what is learned, and how is it learned? *Current Directions in Psychological Science*, 24(3), 190–194.
- Sweller, J. (2016). Cognitive load theory, evolutionary educational psychology, and instructional design. In D. C. Geary, & D. Berch (Eds.), *Evolution and children's cognitive and academic development* (pp. 291–306). Springer International. https://doi.org/10.1007/978-3-319-29986-0_9.
- Sweller, J., Ayres, P., & Kalyuga, S. (2011). *Cognitive load theory*. Springer.
- Toub, T. S., Rajan, V., Golinkoff, R. M., & Hirsh-Pasek, K. (2016). Guided play: A solution to the play versus learning dichotomy. In D. C. Geary, & D. Berch (Eds.), *Evolutionary perspectives on child development and education* (pp. 117–141). Springer International.
- Trémolière, B., Gagnon, M.É., & Blanchette, I. (2017). Cognitive load mediates the effect of emotion on analytical thinking. *Experimental Psychology*, 63, 343–350. <https://doi.org/10.1027/1618-3169/a000333>
- Tricot, A., & Sweller, J. (2014). Domain-specific knowledge and why teaching generic skills does not work. *Educational Psychology Review*, 26(2), 265–283. <https://doi.org/10.1007/s10648-013-9243-1>
- Valiña, M. D., & Martín, M. (2016). The influence of semantic and pragmatic factors in Wason's selection task: State of the art. *Psychology*, 7, 925–940. <https://doi.org/10.4236/psych.2016.76094>
- Van Gog, T., Paas, F., Marcus, N., Ayres, P., & Sweller, J. (2009). The mirror neuron system and observational learning: Implications for the effectiveness of dynamic visualizations. *Educational Psychology Review*, 21(1), 21–30. <https://doi.org/10.1007/s10648-008-9094-3>
- Wason, P. C. (1966). Reasoning. In B. M. Foss (Ed.), *New horizons in psychology* (pp. 135–151). Penguin Books.
- Youssef, A., Ayres, P., & Sweller, J. (2012). Using general problem-solving strategies to generate ideas in order to solve geography problems. *Applied Cognitive Psychology*, 26(6), 872–877. <https://doi.org/10.1002/acp.2888>