Using Primary Knowledge in Unpopular Statistics Exercises

Florence Lespiau, André Tricot

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Abstract

Human cognitive architecture has evolved throughout history, thus facilitating the processing of certain types of knowledge that emerged early on in evolution and that have an adaptive benefit (e.g., recognizing faces or food). Despite its complexity, primary knowledge is processed almost effortlessly, as opposed to secondary knowledge which developed later during the course of evolution and which requires extra cognitive resources and motivation for processing (e.g., "academic" knowledge, such as mathematics or grammar). Primary knowledge also constitutes the basis for secondary knowledge. Using primary knowledge to encourage individuals to invest in a task that is not motivating has therefore been used in recent studies as a promising avenue of research. This study presents 3 experiments in which university students had to complete statistics exercises — statistics being renowned as a difficult discipline typically disliked by students. The task presented problem-solving exercises which were identical in structure but which differed in content, by referring to either primary or secondary types of knowledge. Primary knowledge content, particularly when presented first, enhanced performance and efficiency while maintaining motivation during problem solving. Participants appeared to be unaware of this positive effect. By contrast, secondary knowledge content had a negative effect on performance and seemed to reduce motivation when presented first. These findings suggest that the use of easy-to-process primary knowledge can enhance learning — simply by manipulating task content and presentation order.

Keywords Primary/secondary knowledge · Evolutionary approach · Motivation · Learning · Statistics problem solving

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Introduction

In education, evolutionary psychology — like evolutionary theory —faces an epistemological challenge: theory is based on inductive reasoning and descriptive methods, both considered incompatible with experimental methods and falsification reasoning. Epistemologist Karl Popper, for example, struggled with this issue. He wrote in the early 1970s that "a considerable part of Darwinism is not of the nature of an empirical theory, but it is a logical truism," i.e., a tautology (Popper, 1972, p. 69). He also stated that "the theory of natural selection is not a testable scientific theory, but a metaphysical research programme" (Popper, 1974, p. 168). Yet 4 years later, he contradicted these earlier claims: "I have changed my mind about the testability and logical status of the theory of natural selection; and I am glad to have an opportunity to make a recantation" (Popper, 1978, p. 345).

Today, in evolutionary educational psychology, it is crucial to use experimental methods and falsification reasoning in order to dismiss claims that its research program may be speculative or even metaphysical. There are many ways to achieve this: one is to test a simple hypothesis, whereby the same learning task may result in different performance based on whether participants are using biological primary knowledge or secondary knowledge. In order to further elaborate on this hypothesis, we first need to explain biological primary and secondary types of knowledge.

Biological Primary vs. Secondary Types of Knowledge

Geary (2007, 2008, 2012; Geary & Berch, 2015, 2016) proposed a distinction between biological primary knowledge — characterized as old, having developed since the beginnings of homo sapiens, e.g., self-awareness, face recognition, spoken language, theory of mind — and biological secondary knowledge —characterized as recent, having developed a few thousand years ago, e.g., written language and mathematics. These two types of knowledge are posited as having distinct properties. Specifically, primary knowledge is acquired unconsciously, its processing is fast, low cost in terms of cognitive resources and it is inherently motivated — indeed, our cognitive architecture has evolved to facilitate the acquisition of this type of knowledge. Primary knowledge is instrumental to adaptation and is relevant to folk psychology (e.g., self-awareness, face recognition, facial expressions, speech, group dynamics, theory of mind), folk biology (e.g., fauna, flora, food), and folk physics (e.g., navigation, sense of time, tool use). On the other hand, secondary knowledge is understood to require a long period of learning, due to the fact that our cognitive architecture did not have sufficient time to adapt to it. Its processing is therefore slow, high cost in terms of cognitive resources and it is not inherently — or genetically —motivated. This perspective provides a general framework in educational psychology and has been adopted in cognitive load theory (Sweller, 2021). It is important to distinguish biological primary and secondary types of knowledge in order to specify what learning is and how it operates (Sweller, 2015). There are seven main differences:

Type of difference	Explanation
1. Adaptive value	Primary knowledge corresponds to a human ability to adapt to the environment and to change in that environment. Over the course of their history, social groups may create schools to address the limitations of adaptive learning. By attending school, children in these groups are able to acquire knowledge that does not correspond to their daily lives, but that may later become useful in dealing with complex society (Geary, 2008)
2.The difference between the learning goal and the learning task	In adaptive learning, individuals do what they learn and learn what they do. Children learn to speak by talking and listening. With secondary knowledge, such adaptive learning does not work. It seems that in most cases, school-based learning relies on the distinction between what a student does (e.g., performing a task such as reading) and why she or he does it (e.g., to learn to read) (Sweller et al., 2019)
3. The importance of attention	The adaptive learning of primary knowledge is implicit: hence, humans learn without knowing what they are learning, or even that they are learning. This type of learning does not require any attentional effort, due to inherent constraints that guide attention (Geary, 2008). By contrast, the learning of secondary knowledge is explicit and requires attentional resources
4. Learning processes	The adaptive learning of primary knowledge resides in the non-voluntary and automatic detection of regularities in the environment; whereas the learning of secondary knowledge is based on deliberate, conscious, and costly practice and it may require instruction
5. Learning situations	Adaptive learning is based on immersion and is further aided by social play and by exploring the environment and its objects (Geary, 2008); whereas the learning of secondary knowledge is based on complex tasks such as problem-solving, worked examples, reading or listening to a teacher's explanations (Sweller et al., 2019)
6. Motivation	Adaptive learning is not concerned with motivation. By contrast, secondary knowledge, arguably non-essential, makes greater attentional demands, and as a result, motivation plays an essential role in secondary knowledge learning. Students' motivation often needs to be supported by one or more third parties, such as parents, teachers or peers (Geary & Berch, 2016)
7. Generalization	The adaptive learning of primary knowledge is easily generalized. As far as secondary knowledge learning is concerned, it is exactly the opposite: students often have great difficulty in making generalizations. Indeed, academic knowledge is essentially domain-specific (Tricot & Sweller, 2014)

This set of differences is so important that, all things being equal, an experimental approach is a real challenge. One possibility is to use primary knowledge and skills in order to enhance the acquisition of secondary knowledge (Ginns & King, 2021; Wang et al., 2021). Indeed, primary knowledge facilitates the acquisition of secondary knowledge: primary mechanisms increase working memory capacity and reduce the impact of cognitive load, hence promoting learning (Glenberg et al., 2011; Kirschner et al., 2011; Paas & Ayres, 2014; Paas & Sweller, 2012; Ping & Goldin-Meadow, 2010; Van Gog et al., 2009; Youssef et al., 2012). But there is another way to take up the challenge of experimental hypothesis-testing in evolutionary educational psychology, which we now turn to.

One Task, Two Knowledge Types

As primary and secondary knowledge refer to different experiential domains, it is possible to present the same exercise (i.e., same structure) with either primary or secondary knowledge (i.e., different contents). For example, consider the following conditional puzzle:

If A, then B
B
A?

Here, the participant must make a decision as to the existence of *A* based on the first two lines. The same puzzle can be formulated in reference to primary knowledge, such as food:

In a community in Jamaica, if an ugli is picked when it is red, then it is peeled in order to be eaten
In a community in Jamaica, an ugli has been peeled in order to be eaten
Was this ugli picked when it was red?

Yet again, it can be presented in reference to secondary knowledge, such as grammar rules[1]:

In Quenya, if a strong verb is conjugated in the perfect tense, then this strong verb ends in –ie.
In Quenya, this strong verb A ends in –ie
Is this strong verb A conjugated in the perfect tense?

Note that these two puzzles can be solved without any prior knowledge of uglis in Jamaica, or of Quenya verb grammar, because these are hypothetical facts.

In a set of experiments, Lespiau and Tricot (2018, 2019) asked university and high school students (N = 714) to solve logic puzzles requiring secondary knowledge access. Each puzzle was presented in reference to either primary knowledge content (e.g., rules about made-up foods and animals) or to secondary knowledge content (e.g., fictitious mathematics and grammar rules), as in the example above. In 2 experiments (Lespiau & Tricot, 2018), participants were asked to solve 24 logic exercises, including 12 using primary knowledge content and 12 using secondary knowledge content. In 3 experiments (Lespiau & Tricot, 2019), participants were asked to solve 24 logic exercises, with the same variation in content presentation. The experimental design included a training phase and a test phase. The 5 experiments measured performance on problem solving. Subjective measures were also analyzed, e.g., emotional engagement, motivation, confidence, and perceived cognitive load.

Results showed that solving the same logic puzzle is affected by knowledge contents. Primary knowledge content resulted in better performance, promoted

[1] Formal description of the structure of language.

emotional and cognitive engagement, boosted confidence, and reduced perceived cognitive load. Primary knowledge does not require content familiarity in order to trigger motivation and efficient processing. In addition, there was a significant order effect. When primary knowledge content exercises were presented first, performance on secondary knowledge content exercises was more accurate and perceived cognitive load was lower. By contrast, when secondary knowledge content exercises were presented first, both performance and emotional engagement were poorer. The use of secondary knowledge might induce tiredness or cause individuals to disengage more readily than in primary-knowledge test conditions. When adding extra cognitive load (e.g., by changing the word order or by simultaneously adding a Dot Memory Task), performance on secondary knowledge content exercises suffered whilst performance on primary knowledge content exercises improved.

Additional experiments (Lespiau, 2017; Lespiau & Tricot, 2022) (N = 811) have since replicated these results. Presenting a logic puzzle with primary knowledge content improves performance by an average of 10%, compared with secondary knowledge content. This positive effect of primary knowledge content is observed on every subjective measure. In the present paper, we aim to replicate these results in a domain that represents somewhat of a pedagogical nightmare: the teaching of statistics. And perhaps we are not alone in getting poor results with our students.

Learning Statistics and Motivation

Learning statistics can be difficult for many students. Previous studies emphasize (a) the effect of attitudes towards statistics as a main source of difficulty in learning statistics (Cashin & Elmore, 2005). Other approaches emphasize the major role of (b) intrinsic difficulties pertaining to statistics and probabilistic reasoning, often linked to misconceptions and faulty heuristics, but also of (c) prior education in mathematics, showing that pre-service and in-service K-12 teachers encounter difficulties in understanding and teaching core ideas on probability and statistics, or again of (d) affect (see Garfield & Ben-Zvi, 2007 for a review).

Other studies also associate this difficulty in learning statistics to poor motivation: many students believe that they are not able to learn statistics (i.e., expectancy) and that statistics is useless, or meaningless (i.e., value). According to the expectancy value theory of motivation, studies on maths education show that helping students increase their expectation beliefs might lead to better achievement, and helping students increase their value perception might lead to improved continued interest. Acee and Weinstein (2010) designed a value-reappraisal study to help students reappraise more positively the value they placed on developing statistical knowledge and skills. Students were presented with messages about the importance of becoming an intelligent consumer of statistics in everyday life (i.e., attainment value), academic and professional uses of statistics (i.e., utility value), and the intrinsic enjoyment of learning statistics (i.e., intrinsic value). A total of 82 college students were randomly assigned to the value-reappraisal group and to the control group, in a pre-test and post-test design. The study reported statistically significant gains for the value-reappraisal group on both task values (i.e., perceived value of course tasks) and on

endogenous instrumentality (i.e., perceived usefulness of acquiring knowledge and skills for the attainment of future goals), in both the pre-test with immediate post-test session and in the pre-test followed by a 2-week delay post-test session. However, no results on statistics performance and learning were reported.

Other studies have sought to improve motivation in learning statistics, such as Bayer (2016) who designed guided project-based learning activities. Others have tried to improve statistics learning and motivation through peer-tutoring (Elbulok-Charcape et al., 2019). But the results did not show a clear improvement in learning and motivation (instead, only the one might improve, or indeed the other).

In sum, the literature shows that statistics is difficult to teach and to learn, and it further demonstrates that improving teaching and learning in this domain is complex.

The Present Study

As statistics corresponds to secondary knowledge, our aim in the present study is to test whether a statistics exercise containing primary knowledge results in better performance and motivation, compared with the same statistics exercise containing secondary knowledge. In other words, we attempt to replicate the positive effects of primary knowledge content, previously obtained with logic puzzles, here with statistics exercises.

Experiment 1

The first experiment sought to use knowledge types by changing the contents of the exercise without affecting its structure in order to improve performance on and motivation for statistics exercises.

Method

Participants

Participants were 89 second-year psychology students in France (13 men, 74 women, 2 non-binary, mean age 29.3 ± 10.8) enrolled on a "statistics and measurements" course. Using a self-assessed visual analog scale of 0 to 100, participants rated their enjoyment of the "statistics and measurements" course at 55.6/100 (± 26.8), their ease in the course at 43.9/100 (± 22.5), their personal level in statistics and measurements at 46.4/100 (± 20.4), and their level in mathematics at 43.9/100 (± 28.1). No significant differences were observed across these variables in the two experimental conditions. Of the 89 participants, 54 did not take a break during the experiment; 4 had done more than 16 statistics exercises prior to participating and 6 had never done any (except in compulsory courses). In addition, 74 felt that the study had helped them to better understand statistics and experimental techniques (e.g.,

training proposal, clearer instructions than in classic exercises, more comprehensive questions).

Materials

This experiment presented two exercises modelled on the end-of-semester exam. Each exercise corresponded to the learning acquired during the semester by the participating students. The first exercise consisted of 14 questions (4 multiple choice questions, henceforth MCQ, and 10 short answer questions, henceforth SAQ) scored out of 27.5 points; and the second exercise consisted of 9 MCQs scored out of 9 points. Points were not deducted in the scoring of the exercises. Final scores were converted to percentages. Designing the exercises meant reflecting on experimental procedures (e.g., formulating hypotheses, identifying the independent and dependent variables, and the variables to be controlled, deciding on the type of experimental design) and reflecting on statistics itself (e.g., determining the best statistics test to use — the *t*-test in this experiment —deciding on manual calculation and on an actual *t*-test, reading software outputs, and writing following scientific standards).

We varied the contents of the exercises using either primary knowledge (e.g., information regarding food or animals) or secondary knowledge (e.g., information regarding grammar or mathematics). For example, an exercise might present a situation as follows:

> Researchers are studying whether *taking care of specific animals/using specific verb forms* has a positive effect on individuals. In particular, they think that doing so has a positive effect on self-esteem. According to them, *taking care of cats/using the subjunctive mood* improves self-esteem. They therefore asked 42 participants (20 women and 22 men) aged around 30 to participate in a day *at an animal shelter/writing short stories*. On that day, 21 participants (10 women and 11 men) *took care of dogs* and the remaining 21 took *care of cats (e.g., feeding them, washing them, checking their health, playing with them)*/21 participants wrote their stories *using the indicative mood only* and the remaining 21 wrote *using the subjunctive mood only (e.g., qu'ils aillent, que vous eussiez, que tu prisses*[2]*)*.

In the other exercise, researchers were studying the effect of the type of food consumed relative to a given variable "x" by comparing individuals who ate either cake (e.g., cookie, pie) or fruit (e.g., apple, banana) — both tapping into primary knowledge — vs. the effect of the type of mathematical exercise performed relative to a given variable "y" by comparing individuals who solved either equations (e.g., of the type $2(4y + 1) = 3y$, $y = ax + b$) or trigonometry exercises (e.g., applying the Pythagorean theorem, the cosine rule) — here tapping into secondary knowledge.

[2] These are examples of subjunctive mood use in French. It corresponds to "that they should/ would/ might go" in English.

Procedure

All the students enrolled on the "statistics and measurements" course were given the opportunity to participate in the experiment, which was presented as optional online training for their exams. At the start of the experiment, participants were informed that they could use their course notes (including *t*-test formulas and distribution tables) and that the right answers would be given at the end.

Each exercise was presented on a single webpage, one after the other, with no possibility of going back. Each participant was randomly given primary knowledge contents only (n = 43) or secondary knowledge contents only (n = 46). After each exercise, participants were asked to provide feedback using visual analog scales (0 to 100) on how much they had "enjoyed doing the exercises" (i.e., emotional investment), how much they had "wanted to find the right answers" (i.e., cognitive engagement), how "confident they felt about their answers" (i.e., confidence), and how much they agreed with the following 3 statements: "the task was complex," "the exercise demanded a lot of concentration" and "the experiment was very easy" — i.e., perceived cognitive load. The two scores reported for each variable were aggregated in order to analyze them as overall measures (unless otherwise specified). Feedback answers were scored and converted into percentages. In addition, the time taken to complete the exercises was recorded in order to estimate the performance/time ratio, that is, participants' efficiency on the task relative to knowledge type. Finally, participants rated their willingness to continue with the statistics exercises (from 0 to 100), their preference for either primary or secondary knowledge content type, their learning experience as a result of their participation, and their actual level in statistics and mathematics.

Data analysis

We expect primary knowledge content to improve performance and efficiency on statistics exercises as well as boost motivation. To test this hypothesis, we used between subjects *t*-tests — only the data from participants who did not take a break were used to test efficiency, i.e., the performance/time ratio (n = 54) —and calculated the difference between actual performance and confidence feedback scores to provide an indicator of performance self-assessment (reported *p*-values are two-way ones). We also conducted Pearson correlations to check the direct influence of the statistics level estimates as well as ANCOVAs, ANOVAs and Tukey post-hoc tests to examine the influence of knowledge type on performance relative to the level estimates. For the latter analyses, the statistics level estimates were coded as ordinals (low for estimated levels of [0; 40[n = 13, medium for [40; 60] n = 34, and high for [60; 100] n = 25). Means were annotated M and standard deviation (±). The free software R 3.3.2. was used for the analyses.

Table 1 Results from the between *t*-tests (with two-way *p*-values) showing the influence of knowledge type on the main dependent variables in experiment

	Primary knowledge $M(\pm SD)$	Secondary knowledge $M(\pm SD)$	$t(87)$	p	Cohen's d
Performance (%)					
Overall	56.3(± 13.4)	48.4(± 17.4)	2.41	0.008	0.51
Exercise 1	51.6(± 14.0)	44.5(± 17.8)	2.09	0.02	0.44
Ex.1 MCQ (4 items)	81.9(± 20.6)	77.7 (21.8)	0.94	0.34	0.20
Ex.1 SAQ (10 items)	47.2(± 14.7)	39.6(± 18.2)	2.15	0.02	0.45
Exercise 2	72.8(± 17.7)	62.0(± 18.5)	2.81	0.003	0.59
Enjoyment from the exercises	56.2(± 27.4)	55.6(± 24.3)	0.11	0.91	0.02
Desire to find the right answers	84.1(± 13.7)	76.4(± 16.6)	2.38	0.01	0.50
Confidence	41.9(± 25.3)	38.1(± 23.6)	0.72	0.47	0.15
Perceived cognitive load	61.7(± 13.6)	62.9(± 12.9)	− 0.41	0.67	0.08

Results

The higher the statistics level estimate, the better the performance ($r = 0.44$, $p < 0.001$), enjoyment ($r = 0.52$, $p < 0.001$), and confidence ($r = 0.59$, $p < 0.001$), and the lower the perceived cognitive load ($r = -0.41$, $p < 0.001$). Results relating to the desire to find the right answers are not significant ($r = 0.17$, $p = 0.10$) as most participants were very motivated.

In contrast with secondary knowledge content, primary knowledge content enhances overall performance and the wish to find the right answers — medium effect size in both cases (see Table 1). Performance on exercises 1 (SAQs) and 2 (MCQs) benefited from primary knowledge content. The time spent on the exercises was not affected by knowledge type ($M = 3109.9$ s ± 5376.2 for EXERCISE 1, and $M = 501.2$ s ± 330.3 for exercise 2). However, the analyses for exercise 2 show a greater performance/time ratio with primary knowledge ($M = 0.19 \pm 0.09$) than with secondary knowledge ($M = 0.14 \pm 0.06$) ($t(52) = 2.35$, $p = 0.02$, $d = 0.65$). Participants were thus more efficient in Exercise 2 when using primary rather than secondary knowledge. In exercise 2, the difference between actual performance and confidence scores was marginally influenced by knowledge type, as primary knowledge appears to trigger a greater underestimation of one's performance ($M = 29.2 \pm 27.3$) than does secondary knowledge ($M = 21.1 \pm 26.7$) ($t(52) = 1.41$, $p = 0.16$, $d = 0.30$). The effects of knowledge type on the other variables were not significant, although the descriptive trends seemed to be consistent with our hypotheses (see Table 1) (note that these trends were also present when examining the exercises data separately). Statistics level estimates do not show a significant effect of knowledge type on the observed variables — whether we consider the raw quantitative scores or the low/medium/high coded scores. Thus, knowledge type did not influence participants' responses relative to their level in statistics.

In addition, knowledge type had no effect on participants' willingness to continue doing statistics exercises. However, there is a descriptive trend in favor of continuing

with primary knowledge content (M = 68.2/100 ± 28.5) rather than with secondary knowledge content (M = 63.1/100 ± 29.2) ($t(87) = 0.84$, $p = 0.40$, $d = 0.18$).

Discussion

When exercise content refers to primary knowledge, we observe an improvement in overall performance, in efficiency (exercise 2) and in the desire to find the right answers. In addition, recall that this was not a time-controlled task, that is, participants were free to spend as much time as they wanted on the exercises. Interestingly, their performance was more efficient on exercises containing primary rather than secondary knowledge (see the performance/time ratio in exercise 2). The fact that there was no time-based difference in Exercise 1 may be due to the length and format of the exercise which comprised both SAQs and MCQs.

An interesting fact is that participants were generally all eager to find the right answers even if they only moderately liked statistics, regardless of knowledge type (M = 84.1 ± 13.7 for primary knowledge vs. M = 76.4 ± 16.6 for secondary knowledge). An explanation may be found in feedback answers: participants reported feeling stressed about the upcoming final exam and took part in the experiment in order to revise (this was indeed required of them). This may further explain why we did not observe any significant differences between the use of primary and secondary knowledge on the other variables.

Primary knowledge thus seems to offer an advantage over secondary knowledge for learners faced with exercises that they only moderately enjoy. These findings are therefore encouraging.

Experiment 2

Experiment 2 aimed to confirm these results in an ecological test situation which consisted in a training session for the statistics final exam.

Method

Participants

Participants were 52 second-year psychology students in France (4 men, 47 women, 1 non-binary, mean age was 21.2 ± 4.3) enrolled on a “statistics and measurements” course at the university. On a self-assessed visual analog scale of 0 to 100, participants rated their enjoyment of the “statistics and measurements” course at 59.8/100 (± 21.0), their ease with the course at 57.6/100 (± 20.7), their personal level in statistics and measurements at 58.6/100 (± 16.2), their academic level in mathematics at 54.1/100 (± 21.2), their confidence in successfully completing the exercises at 50.5/100(± 21.5) and in passing the end-of-semester exam at 60.0/100 (± 20.3). There were no significant differences on those ratings across experimental conditions except for the rating of “enjoyment of “statistics and measurements” course.”

Indeed, participants in the primary-knowledge condition ($M = 54.2/100 \pm 23.1$) rated their enjoyment of statistics lower than participants in the secondary-knowledge condition ($M = 65.4 \pm 17.2$) ($t(50) = -1.98$, $p = 0.05$). Of the 52 participants, 42 completed most (and sometimes all) of the exercises presented during the course, 10 completed only a few (or none), and 6 completed other exercises on their own; 41 reported not having enough time to study to partake in the experiment. Finally, 44 participants mentioned finding the experiment useful, in particular because it allowed them to see the type of questions that would be asked in the end-of-semester exam.

Materials

The pen-and-paper test was identical to an end-of-semester exam: it consisted of five exercises (consisting of 19 SAQs with a maximum score of 100 points) addressing the same contents as the exercises in experiment 1 (i.e., questions on variables, test choice, test interpretation). The statistics tests used were either chi-square (independence, conformity or McNemar) or correlations (Pearson or Spearman) in order to correspond to course-based learning outcomes. As in experiment 1, we varied the details in each exercise, as in the examples below:

> Primary knowledge exercise: A dog keeper wants to check that the color distribution of his dogs' fur corresponds to the following proportions: 30% solid black, 5% solid white, 5% solid red, and 60% mixed color.
> Secondary knowledge exercise: A mathematics teacher wants to check that the distribution of his trigonometry exercises corresponds to the following proportions: 30% triangles, 5% rhombuses, 5% circles, and 60% mixed figures.

Other examples included reference to the relation between types of chocolate being eaten (e.g., hazelnut, milk, or fruit chocolate) and arguing during meetings (i.e., a primary knowledge scenario) vs. the relation between types of adjectives being used (e.g., numeral, superlative or attributive) and arguing during meetings (i.e., a secondary knowledge scenario). The exercises were always identically structured, the only difference being the knowledge type of reference (i.e., either primary or secondary knowledge).

Procedure

Participants attended a class session set aside for exam training — effectively the last class of the semester. Although they took part in the training session, provided us with the data from their exercises on a voluntary basis. The session unfolded as follows. First, each participant was given a handout complete with instructions, calculation formulas, distribution tables, and the actual questions. Participants then had a maximum of 2 h to complete the exercises in realistic exam conditions. Finally, the remaining hour of class time was spent reviewing and discussing the exercises.

Before beginning the exercises, participants were asked to rate on a visual analog scale (0 to 100, with paper centimeters converted to percentages) their level of confidence in their own ability to complete the exercise, their personal level in

mathematics and statistics, their fondness for statistics, and their likely ability to pass the final exam due to take place a month later. We chose to get these self-assessment measures prior to participants completing the exercises in order to avoid any effect of their actual performance on these estimates. Participants then completed the exercises using either primary or secondary knowledge content (n = 26 in each condition), as in experiment 1.

After completing the exercises, participants answered demographics and visual analog scale questions relating to their enjoyment of the exercises, their desire to get the right answers, their confidence in their performance, their perception of the cognitive load, and their wish to continue doing similar exercises (i.e., same items as in experiment 1). In addition, we again asked them to give an estimate of their personal level in mathematics and statistics, their fondness for statistics and their likely ability to pass the end-of-semester exam. The objective was to allow for a before/after comparison and to study the effects of knowledge types in greater depth.

Data analysis

Data analyses were similar to those in experiment 1. In addition, we used linear mixed effects models and contrast analyses to examine the influence of knowledge types and of the time measurements (before or after the exercises), and importantly of the fondness for statistics.

Results

The higher the statistics level estimate, the better the performance (r = 0.62, $p < 0.001$), enjoyment ($r = 0.37$, $p = 0.006$), and confidence ($r = 0.50$, $p < 0.001$) and the lower the perceived cognitive load (r = -0.39, p = 0.003). Results relating to the desire to find the right answers are not significant ($r = 0.12$, $p = 0.37$) as most participants were very motivated.

In contrast with secondary knowledge content, primary knowledge content enhanced overall performance (medium effect size) but there were no significant effect on the other dependent variables (see Table 2). The benefits of primary knowledge content were particularly noticeable in the first three exercises. Participants' statistics level estimates did not result in knowledge type having a significant effect on the observed variables. By comparing the pre- and post-task measurements, we found an interaction between the time measurement and knowledge type in relation to participants' fondness for statistics ($F(1,50) = 8.41$, p = 0.005). Participants reported less enthusiasm for statistics after secondary knowledge exercises ($p = 0.01$) even though they had initially reported a greater fondness for statistics than participants in the primary knowledge test condition ($p = 0.05$) (see Fig. 1).

Furthermore, knowledge types had no influence on the willingness to continue doing statistics exercises. However, there is a descriptive trend in favor of continuing with primary knowledge exercises ($M = 65.3/100 \pm 15.8$) rather than with secondary knowledge exercises ($M = 60.7/100 \pm 23.8$) ($t(50) = 0.82$, $p = 0.41$, $d = 0.23$).

Table 2 Results from the between *t*-tests (with two-way *p*-values) on the influence of knowledge type on the main dependent variables in experiment 2

	Primary knowledge $M(\pm SD)$	Secondary knowledge $M(\pm SD)$	$t(50)$	p	Cohen's d
Performance (%)					
Overall	63.6 (± 18.0)	49.6(± 21.8)	2.51	0.01	0.69
Exercise 1	50.2(± 21.2)	35.5(± 13.0)	3.02	0.004	0.83
Exercise 2	69.2(± 22.5)	48.6(± 30.5)	2.77	0.008	0.76
Exercise 3	78.9(± 25.8)	63.1(± 31.0)	1.99	0.05	0.55
Exercise 4	53.0(± 27.7)	41.2(± 33.7)	1.37	0.17	0.38
Exercise 5	54.8(± 25.0)	47.3(± 25.5)	1.06	0.29	0.29
Enjoyment from the exercises	59.3(± 14.5)	58.8(± 22.2)	0.09	0.92	0.02
Desire to find the right answers	82.1(± 12.0)	80.4(± 16.6)	0.41	0.67	0.11
Confidence	50.8 (± 22.8)	50.0(± 18.8)	0.14	0.88	0.04
Perceived cognitive load	55.0(± 20.0)	58.1(± 18.4)	− 0.57	0.57	0.16

Discussion

Experiment 2 provides another favorable argument according to which performance on a statistics task can benefit from the use of primary knowledge content. The fact that participants' fondness for statistics lessened when they were dealing with secondary knowledge content suggests that this type of knowledge may have a negative effect on motivation. In this experiment, participants who were exposed to secondary knowledge content initially reported a greater fondness for statistics than those who were given primary knowledge content exercises. This initial difference might

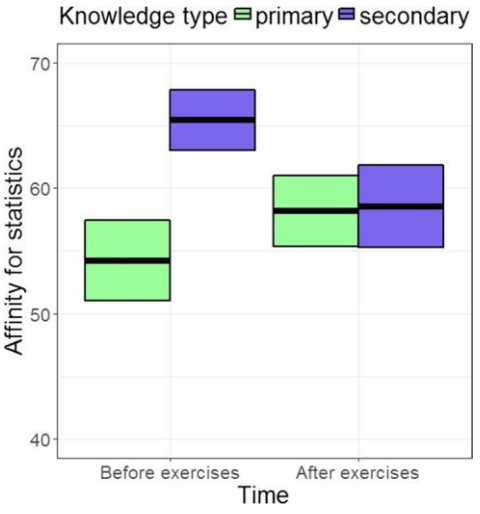

Fig. 1 The influence of knowledge type relative to self-assessment time (before vs. after the exercises) on the fondness for statistics (experiment 2). Boxplots represent the mean and 95% of the confidence interval

be in part responsible for the lesser fondness for statistics observed after completing the exercises. However, the fact remains that secondary knowledge content led to participants being less fond of statistics, whereas this was not the case in the primary knowledge content condition (in fact, descriptively speaking, we found the opposite to be true).

As in experiment 1, knowledge type did not significantly influence enjoyment from the exercises or the desire to find the right answers. All participants felt motivated to find the right answers and were reasonably confident in their performance. This may be explained by sampling characteristics. Indeed, the 52 participants came from a cohort of 233 students enrolled in the statistics course. Students who chose to take part in the experiment were therefore motivated students who wanted to increase their chances of passing the end-of-semester exam (indeed, the experiment afforded them practice, self-assessment, and a valuable insight into exam questions).

The beneficial effects of primary knowledge content on performance are particularly noticeable in the first three exercises of the test (note that there were five exercises in total). Given previous results concerning exercise contents (Lespiau & Tricot, 2019), we propose the following interpretation: at the beginning of the task, participants performed better with primary knowledge content than with secondary knowledge content. The primary knowledge effect then began to subside as a result of the growing training effect from secondary knowledge content. This interpretation is based on the fact that participants completed the exercises in a set order without the ability to go back (this is further shown in experiment 2). However, the order in which knowledge type is being presented may be an important factor to consider. This is what we propose to test in a third experiment.

Experiment 3

Experiment 3 aimed to further examine the positive effects of primary knowledge content and to investigate the order of presentation of knowledge types. It is hypothesized that presenting primary knowledge before secondary knowledge content enhances participant engagement and performance.

Method

Participants

Participants consisted of 74 psychology students in France (43 s year, 31 third year; 7 men, 65 women, 2 non-binary, mean age was 30.4 ± 9.8) attending "statistics and measurements" courses. On a self-assessed visual analog scale of 0 to 100, participants rated their enjoyment of the statistics university course at 60.9/100 (± 25.3), their ease with the course at 50.8/100 (± 26.2), their level in statistics at 51.1/100 (± 20.4) and their level in mathematics at 49.1/100 (± 23.5). No significant

differences were observed across experimental conditions (between-subjects) on those ratings. Of the 74 participants, 42 did not take a break during the experiment; 23 participants were presented with primary knowledge content first, and 19 with secondary knowledge content first; 8 had done more than 16 statistics exercises before participating and 27 had never done any (except in compulsory courses). In addition, 66 felt that the study had helped them to better understand statistics or experimental techniques (e.g., stress-free training, review of key concepts, knowledge transfer in exercises differing from those they were used to). When asked to select their favorite exercise, 31 participants selected the primary knowledge exercise, 15 the secondary knowledge exercise, and 28 preferred had no preference.

Materials

Participants had to solve two identically structured exercises online. The questions corresponded to their course-based learning outcomes. For second-year students, the exercises contained 12 questions each, including 2 MCQs, for a maximum score of 20 points. For third-year students, the exercises contained 17 questions, including 3 MCQs, for a maximum score of 31.5 points. Performance on each exercise was converted to a 100-point score to allow for comparison. For both second- and third-year participants, the two exercises were composed of the same questions. These were similar to the ones in previous experiments, e.g., identification of hypotheses, of the independent and dependent variables, test choice, test calculation, interpretation and writing. One exercise proposed a within-subjects design and the other a between-subjects design. Primary knowledge content exercises dealt with food (e.g., cake, fruit and vegetables, using several examples) and secondary knowledge exercises dealt with verb moods (e.g., imperative, subjunctive and indicative moods, using several examples).

Procedure

Experiment 3 was similar to the first two experiments in that it presented identically structured puzzles containing either primary or secondary knowledge content. However, knowledge type was used as a within-subjects factor and presentation order as a between-subjects factor. Experiment 3 was similar to experiment 1 in terms of procedure and instructions given to the participants, except that the presentation order of the exercises changed. Participants were randomly assigned to either the primary-knowledge-first condition (n = 35) (n = 18 in the between-subjects design; n = 17 in the within-subjects design) or to the secondary-knowledge-first condition (n = 39) (n = 19 in the between-subjects design; n = 20 in the within-subjects design).

Each exercise was presented online on several consecutive pages, without any possible backtracking (2 pages for second-year students, 4 pages for third-year students). The elements necessary for solving the exercises were systematically displayed on the current page. At the end of each exercise, we measured the time taken to complete the task, and analyzed performance, enjoyment, the desire to find the right answers, participants' confidence in their performance and perceived cognitive

Table 3 Results from linear mixed-effects models on the influence of knowledge types on the main dependent variables in experiment 3

	Primary knowledge $M(\pm SD)$	Secondary knowledge $M(\pm SD)$	*Wald* χ^2	*p*	Estimate (SE)
Performance (%)	65.5(± 18.5)	58.6(± 19.1)	18.43	< 0.001	− 0.44(0.12)
Enjoyment from the exercises	57.9(± 23.4)	57.4(± 25.2)	0.21	0.64	− 0.34(0.12)
Desire to find the right answers	76.0(± 21.4)	76.4(± 17.7)	0.001	0.93	− 0.52(0.15)
Confidence	39.8(± 26.0)	40.5(± 24.3)	0.03	0.83	− 0.22(0.12)
Perceived cognitive load	65.3(± 16.5)	63.3(± 13.3)	1.49	0.22	0.01(0.15)

load. As in experiment 1, at the end of the task, participants answered questions about their preferences, their ease with the exercises, their wish to continue practicing with either primary or secondary knowledge contents, and they provided demographics.

Data analysis

Linear mixed-effects models and contrast analyses were used to analyze scaled data. The Wald χ^2, estimate and its standard error (SE) were reported for the main analyses. We also used within *t*-test to analyze participants' wish to continue with either type of exercise. As in the previous experiments, we used Pearson correlations to check the effect of statistics level estimates. Note that only the data from participants who did not take a break were used to examine efficiency on the test, using the performance/time ratio (n = 42).

Results

The higher the participant's statistics level estimate, the better the performance (r = 0.46, p < 0.001), the enjoyment (r = 0.58, p < 0.001), the wish to find the right answers (r = 0.34, p < 0.001), and confidence in their performance (r = 0.65, p < 0.001), and the lower the perceived cognitive load (r = − 0.33, p < 0.001).

Participants demonstrated better performance on exercises using primary knowledge rather than secondary knowledge content (see Table 3). They also performed better when primary knowledge was presented first rather than when secondary knowledge was presented first (see Table 4). Statistics level estimates did not have a significant effect on the independent variables.

Specifically, when primary knowledge was presented first, participants performed better on primary knowledge exercises (M = 71.1 ± 15.3) than on secondary knowledge exercises (M = 62.5 ± 19.8) (p < 0.001). They also performed better when secondary knowledge was presented first (M_{K1} = 60.5 ± 19.8 vs. M_{K2} = 55.1 ± 21.4) but to a lesser extent (p = 0.02). Performance was poorer on primary knowledge

Table 4 Results from linear mixed-effect models on the influence of presentation order on the main dependent variables in experiment 3

	Primary knowledge first	Secondary knowledge first	*Wald* χ^2	*p*	Estimate (SE)
	M(± SD)	*M*(± SD)			
Performance (%)	66.8(± 15.9)	57.8(± 20.7)	5.13	0.02	– 0.55(0.22)
Enjoyment from the exercises	58.7(± 23.0)	56.7(± 25.5)	0.15	0.69	– 0.39(0.23)
Desire to find the right answers	79.0(± 17.1)	73.7(± 21.4)	1.87	0.17	– 0.77(0.22)
Confidence	40.8(± 22.1)	39.6(± 27.6)	0.04	0.83	– 0.28(0.23)
Perceived cognitive load	63.6(± 15.0)	65.0(± 15.0)	0.19	0.65	0.24(0.23)

questions when these were presented after secondary knowledge questions ($p = 0.01$), while performance on secondary knowledge questions improved when presented after primary knowledge questions (marginal significance, $p = 0.08$) (see Fig. 2). In addition, participants rated their wish to continue with exercises on a topic similar to the primary knowledge questions at 64.6/100 (± 26.8) vs. 60.4/100 (± 27.5) on a topic similar to secondary knowledge questions. The two-way difference was marginal ($t(73) = 1.70$, $p = 0.09$).

Participants who did not take a break had a better performance/time ratio on primary knowledge exercises ($M = 0.033 \pm 0.014$) than on secondary knowledge exercises ($M = 0.028 \pm 0.013$) (estimate = 0.32, SE = 0.17; $\chi^2 = 9.57$, $p = 0.003$). The interaction effect between knowledge type and presentation order was significant relative to this ratio (estimate = -1.46, SE = 0.26; $\chi^2 = 30.82$, $p < 0.001$). When primary knowledge content was presented first, the difference in efficiency between primary

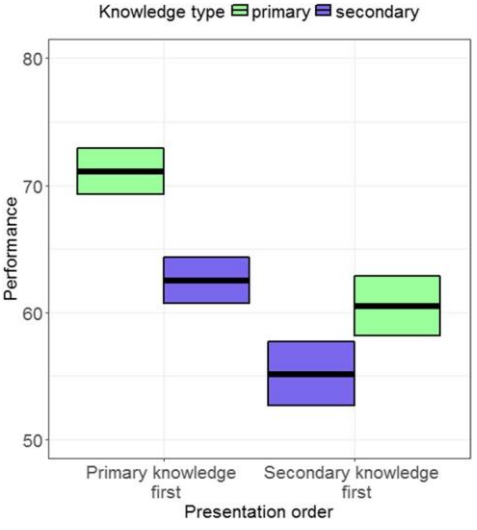

Fig. 2 The influence of knowledge type on performance relative to presentation order (experiment 3). Boxplots represent the mean and 95% of the confidence interval

(M = 0.031 ± 0.011) and secondary knowledge exercises (M = 0.035 ± 0.012) was marginally significant (p = 0.07), whereas when secondary knowledge was presented first, the difference between primary (M = 0.037 ± 0.016) and secondary knowledge exercises (M = 0.021 ± 0.010) was significant (p < 0.001). The difference in efficiency between primary knowledge exercises regardless of the presentation order was not significant (p = 0.10) but it was significant between secondary knowledge content exercises (p < 0.001) (see Fig. 3).

When considering the difference between actual performance and participants' confidence in their performance, the data shows that participants have a tendency to underestimate themselves when dealing with primary knowledge content whether it was presented first (M = 27.5 ± 21.8) or second (M = 24.0 ± 24.5) (p = 0.50). This underestimation is also noticeable in the secondary knowledge exercises when these are presented after primary knowledge content (M = 24.5 ± 22.3), although the difference was not significant (p's > 36). By contrast, participants underestimated themselves to a lesser degree and gave a better estimation of their performance when dealing with secondary knowledge content before primary knowledge content (M = 12.3 ± 20.4) (0.02 < p's < 0.0003).

There is a significant interaction effect of knowledge type and presentation order on the desire to find the right answers (estimate = 1.02, SE = 0.22; χ^2 = 21.50, p < 0.001). Concerning presentation order effects, the data shows that participants were more motivated to find the right answers for exercises that were presented to them first, independent of their content. When primary knowledge content was presented first, participants showed a greater desire to find the right answers for primary knowledge exercises (M = 84.1 ± 5.8) rather than secondary knowledge exercises (M = 73.9 ± 17.0) (p = 0.001). When secondary knowledge content was presented first, participants showed a greater desire to find the right answers for secondary knowledge exercises (M = 78.6 ± 18.2) rather than primary knowledge

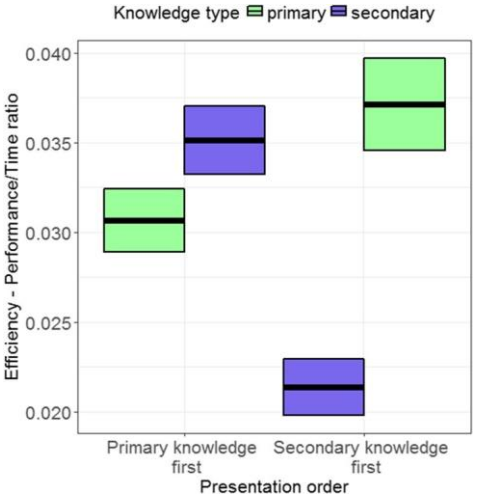

Fig. 3 The influence of knowledge type on the efficiency or performance/time ratio relative to presentation order (experiment 3). Boxplots represent the mean and 95% of the confidence interval

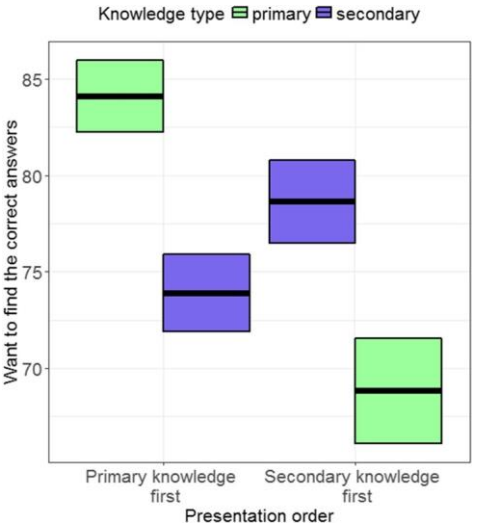

Fig. 4 The influence of knowledge type on the desire to find the right answers relative to presentation order (experiment 3). Boxplots represent the mean and 95% of the confidence interval

exercises ($M = 68.8 \pm 23.3$) ($p = 0.001$). However, participants' motivation to find the right answers to primary knowledge exercises decreased when secondary knowledge content was presented first ($p < 0.001$), whereas there was no difference in motivation for secondary knowledge exercises regardless of presentation order ($p = 0.28$) (see Fig. 4).

There is a significant interaction effect of knowledge type and presentation order on participants' enjoyment of the task (estimate = 0.61, SE = 0.17; $\chi^2 = 13.10$, $p < 0.001$; regarding primary knowledge first $M_{K1} = 63.0 \pm 21.6$ vs. $M_{K2} = 51.5 \pm 23.9$; regarding secondary knowledge first $M_{K1} = 53.4 \pm 24.3$ vs. $M_{K2} = 60.0 \pm 26.4$) and on their confidence in their performance (estimate = 0.47, SE = 0.17; $\chi^2 = 7.69$, $p = 0.007$; regarding primary knowledge first $M_{K1} = 43.6 \pm 22.7$ vs. $M_{K2} = 38.0 \pm 21.5$; regarding secondary knowledge first $M_{K1} = 36.4 \pm 28.5$ vs. $M_{K2} = 42.8 \pm 26.7$). These effects are explained by the fact that it was the first exercises to be completed that generated the most enjoyment and motivation regardless of knowledge type.

Perceived cognitive load was not significantly influenced by the variables at hand (primary knowledge first $M_{K1} = 63.4 \pm 16.2$ vs. $M_{K2} = 63.7 \pm 16.8$; secondary knowledge first $M_{K1} = 67.1 \pm 16.8$ vs. $M_{K2} = 62.9 \pm 12.9$). However, contrastive analyses show a marginal increase in perceived cognitive load in primary knowledge exercises when presented second (compared to secondary knowledge exercises presented first; $p = 0.06$) (see Fig. 5).

Discussion

Participants performed better on exercises using primary rather than secondary knowledge. This confirmed the results of previous experiments. Moreover, overall performance was better when primary knowledge exercises were presented first

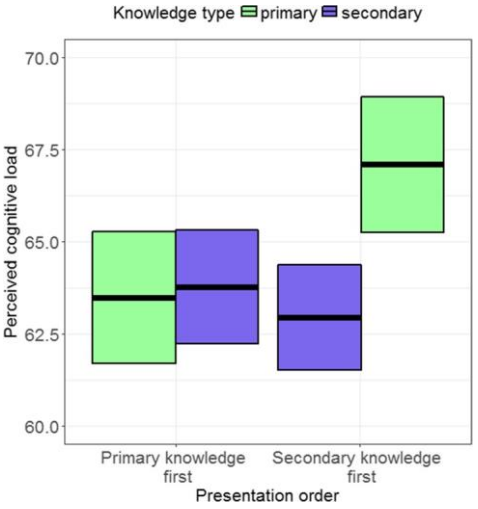

Fig. 5 The influence of knowledge type on perceived cognitive load relative to presentation order (experiment 3). Boxplots represent the mean and 95% of the confidence interval

than when secondary knowledge exercises were presented first. Specifically, considering the interaction effect of knowledge type and presentation order on performance, the repetition of the two exercises seemed to benefit secondary knowledge more than primary knowledge exercises. We may also consider that when secondary knowledge was presented first, then learners' performance was poorer on the following exercise (i.e., primary knowledge in this experiment). The positive effects of primary knowledge (both in terms of content and presentation order) are clearly demonstrated by the performance/time ratio, which provides information about participants' efficiency: learners were rather efficient on primary knowledge exercises regardless of presentation order, whereas training (and the presentation of primary knowledge first) particularly benefited performance on secondary knowledge exercises. Participants also tended to underestimate their performance on primary knowledge exercises (regardless of presentation order) and on secondary knowledge problems presented second. In other words, participants did not expect to perform as well as they in fact did since there was no significant difference in confidence levels. In this case, it is interesting to consider that primary knowledge improved performance without participants being aware of it.

A downside of using secondary knowledge content is further illustrated by the fact that the wish to find the right answers was not influenced by presentation order in secondary knowledge exercises, whereas it was greatly reduced in primary knowledge exercises when these were presented second. In the latter exercises, the data indicated that the perceived cognitive load was marginally higher. The other results were mostly representative of the fact that participants were more confident and enjoyed doing the first exercises (regardless of knowledge type content). The lack of effect of knowledge type on these variables may be attributed to sampling (participants were motivated students seeking training) and to exercise type. Indeed, exercises in experiment 3 (like those in experiment 1) were rather lengthy (comprising

at least 12 questions per exercise) and the solution to each question often depended on the previous one (even though the notation was adapted as the learner advanced). Regardless, it is clear that the use of primary knowledge is a promising avenue of research into factors likely to boost learner performance in and motivation for statistics.

General Discussion

This study sought to use the different knowledge types defined by the evolutionary approach (Geary & Berch, 2016) as surface content in statistics exercises with the aim of enhancing performance, motivation, and learning. The use of primary knowledge content — which is processed effortlessly and is intrinsically motivating —should allow for greater engagement in secondary knowledge exercises such as statistics —which are processed with greater effort and with little motivation (Lespiau & Tricot, 2018, 2019, 2022). In three experiments, participants were given identically structured statistics exercises (i.e., secondary knowledge) with either primary knowledge content (e.g., food, animals) or secondary knowledge content (e.g., grammar and maths). Results show that the use of primary knowledge content enhances performance. Furthermore, when these primary knowledge exercises were presented first, efficiency and performance on the next puzzle improved while motivation was maintained. By contrast, secondary knowledge content reduced performance quality and appeared to lessen motivation when presented first. The positive effects of primary knowledge content appear to be unconscious yet robust. In sum, this study argues in favor of using primary knowledge in learning. Modifying topics and contents, without changing the structure of the target learning point seems to be a promising avenue of further research in education.

Positive Effects of Primary Knowledge Content

The present study reviewed three experiments and confirmed the positive effects of primary knowledge content on participants' problem-solving performance and efficiency (performance/time ratio). These positive effects may further extend to participants' motivation (experiment 1). Primary knowledge content improved participants' performance, especially in the initial exercises (experiment 2). Presenting primary knowledge content first improved participant performance in ensuing secondary knowledge exercises (experiment 3). Secondary knowledge content benefited from a learning effect, and potentially from enhanced transfer when presented second. This was also confirmed by performance/time efficiency ratios relative to presentation order: participants were more efficient on secondary knowledge exercises when these were presented second. Primary knowledge content is therefore beneficial in this type of exercises and using it early on in the task may be a fruitful way to improve secondary knowledge learning.

Negative Effects of Secondary Knowledge Content

By contrast, it may prove less relevant to use secondary knowledge content in learning since it seemed to lower participants' motivation. Secondary knowledge content reduced their fondness for statistics — whereas this fondness tended to increase when primary knowledge was at stake (experiment 2). When secondary knowledge content was presented first, performance suffered as did the desire to get the right answers in ensuing primary knowledge exercises —in comparison with the scores obtained in the primary knowledge first condition. Thus, secondary knowledge had a negative effect on both motivation and performance, while increasing perceived cognitive load in ensuing exercises (experiment 3). These findings are consistent with the evolutionary approach to knowledge, in terms of effort and motivation characteristics (Geary & Berch, 2016; Sweller, 2016) and contribute to existing research on the use of primary knowledge to promote learning (Paas & Sweller, 2012; Youssef et al., 2012; Youssef-Shalala et al., 2014).

The Unconscious Nature of Primary Knowledge Effects

These three experiments thus show that, given the choice between primary and secondary knowledge content, it is better to opt for primary knowledge when addressing problem-solving learning and teaching. However, the cognitive mechanisms at work remain unknown. We suggest that the mechanisms underlying the positive effects of primary knowledge are accessed unconsciously by learners. In the present study, the performance-confidence" indicator showed that participants underestimated their performance on primary knowledge exercises, while there was no difference in perceived confidence between the two knowledge types (that is, participants did not feel particularly more confident on one statistics exercise rather than another). This effect would likely arise as a result of better performance on primary knowledge tasks, which participants would be unaware of. This underestimation of their own performance was also present when secondary knowledge exercises when presented second. Again, this lends support to the existence of positive effects resulting from the use of primary knowledge (experiment 3). The unconscious nature of the mechanisms associated with primary knowledge access could be compared to type 1 mechanisms in dual-process approaches (Evans, 2008; Evans & Stanovich, 2013), even though type 1 and primary knowledge are not the same thing (e.g., reading or multiplying small numbers are type 1 mechanisms for many adults, yet they correspond to secondary knowledge). Type 1 mechanisms are unconscious, implicit, linked to evolutionary rationality and independent from cognitive abilities. Type 2 mechanisms are conscious, explicit, linked to individual rationality and dependent on working memory resources. The ease with which learners process primary knowledge could thus be linked to type 1 mechanisms (i.e., fast and generally efficient). Faced with syllogisms, individuals are less vulnerable to belief bias (theoretically linked to a type 1 response) when the contents referred to primary knowledge (Lespiau & Tricot, 2022). These data support the new parallel/serial hybrid system theories: two type 1 responses would be possible (heuristic intuition and logical

intuition such as sensitivity to the logical structure of arguments) and would have different effects. This difference in strength would make the first answer emerge. The conflict between these two types of responses could lead to the involvement of a type 2 process, which would test the first response (Bago & De Neys, 2017; Pennycook et al., 2015). The specific mechanisms underlying primary and secondary knowledge processing are still largely unknown, but the similarities between mechanism types and knowledge types may prove a promising avenue of research.

These unconscious positive effects of primary knowledge may also be attributed to its ease of processing (Geary & Berch, 2016) which could be mistaken for familiarity. In the experiments presented here, there is no reason to think that participants were more familiar with content relating to primary knowledge than with content relating to secondary knowledge since (i) the exercises were formulated using common everyday terms, and (ii) participants spent most of their time studying and manipulating secondary knowledge such as grammatical rules and mathematics (Beck & Richard, 2010; Guichemerre, 2011). The feeling of fluency when processing primary knowledge may be responsible for this sense of familiarity. This "false" familiarity might be similar to that used in memory research: fluency in information processing is falsely construed as familiarity in cases where the information source is not remembered (Whittlesea et al., 1990). Moreover, familiarity with or prior knowledge of a domain does not influence performance in problem-solving tasks (Lespiau & Tricot, 2018, 2022, e.g., with non-words). In fact, prior knowledge may prove a disadvantage (De Neys et al., 2005). A recent general cognitive model for arithmetic word problems suggests that the main difficulty in solving word problems lies with the semantic congruence between the presentation of the problem and the knowledge needed to solve it (Gros et al., 2020). When the presentation is not congruent with the knowledge needed to solve the problem, then the individual must recode the problem. Arithmetic problems are automatically coded on the basis of non-mathematical knowledge from everyday life (Gros et al., 2021). Familiarity can therefore be a hindrance rather than a help in problem-solving tasks. Although it was not the primary aim of this study, examining the effects of variations in knowledge type familiarity with may lead to a better understanding of the processing mechanisms at work.

The unconscious mechanisms hypothesis receives additional support from the absence of a significant effect of knowledge type on most of the subjective variables — with the exception of the wish to find the right answers. While the descriptive statistics followed the trend of a positive effect of primary knowledge on these variables, participants also tended to prefer primary knowledge exercises — compared with secondary knowledge exercises (experiment 3). It is important to remember that the exercises corresponded to secondary knowledge in terms of structure but varied in content, integrating either surface-level primary or secondary knowledge. It would thus take more exposure than a few exercises could afford to see an influence of knowledge type on the subjective variables — for example, by using the two different types of content throughout the academic year.

Nevertheless, this absence of results on subjective variables was surprising, especially given previous studies on logic puzzles that have showed an important positive effect of primary knowledge on these same variables (Lespiau & Tricot, 2018, 2019,

2022). One explanation may lie with the difference between the problems used (e.g., syllogisms vs. statistics exercises). Indeed, psychology students never — or rarely —work on syllogisms. But the psychology students in the present study had been trained on statistics and therefore had knowledge of the field (i.e., factual knowledge, and knowledge of systems of representation, beliefs and attitudes). Moreover, syllogisms can be solved intuitively — both in terms of a "yes"/"no"/"maybe" type of answer, and of the mechanisms involved (Bago & De Neys, 2017) – whereas statistics exercises require argumentative answers and call upon analytical mechanisms (for instance, via transfer mechanisms). The problem-solving mechanisms used with syllogisms would therefore be dissimilar and much less prone to subjective assessment than the mechanisms used in solving statistics exercises. The present study therefore highlights the need to better understand the cognitive mechanisms involved in the processing of primary and of secondary knowledge.

Knowledge type did not have an effect on the variables being studied based on statistics level estimates. This finding is encouraging in that primary knowledge improves performance and motivation regardless of the level in statistics — consistent with primary knowledge effects observed regardless of individual characteristics (Lespiau & Tricot, 2019). However, participants in the present experiments were generally rather motivated to learn statistics: these participants were the students who wanted to practice since participation in the experiments was on a voluntary basis (including in experiment 2 when the exercises were given during an optional class). Participants did not seem to particularly like answering statistics questions, but they were motivated to find the right answers. Participants often felt more motivated for the exercises they worked on first, regardless of their content (experiment 3). The sampling bias can be fixed with a more ecological design in order to reach a wider range of learners, including those who have little or no motivation for statistics. For example, class sessions could integrate the use of primary knowledge content in training exercises (specifically at the beginning of sessions) and measure its influence on motivation and performance throughout the year, including during final exams. It would also be interesting to use primary knowledge content in the ongoing feedback given to learners on their coursework or as part of worked examples to assess whether primary (vs. secondary) knowledge facilitates the understanding and identification of a common solution rule in statistics exercises. It is also important to note that the data for this study were obtained from psychology students who use basic-level statistics. Further studies may determine whether similar findings are also observed with mathematics students for whom statistics is more central to their learning.

Experiments presented in this paper offer an example of how an evolutionary psychology approach in education can be based on falsifiable hypotheses. The fact that our results are compatible with Geary's distinction between biological primary and secondary knowledge is positive and even compelling. Indeed, a simple change of words in the formulation of an exercise, in reference to either biological primary or secondary knowledge, has an important effect on performance in as complex a domain as statistics learning — even when those words have nothing to do with the statistics exercise itself.

Declarations

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

Conflict of Interest The authors declare no competing interests.

References

Acee, T. W., & Weinstein, C. E. (2010). Effects of a value-reappraisal intervention on statistics students' motivation and performance. *The Journal of Experimental Education, 78*(4), 487–512.

Bago, B., & De Neys, W. (2017). Fast logic?: Examining the time course assumption of dual process theory. *Cognition*, *158*, 90–109.

Bayer, T. J. (2016). Effects of guided project-based learning activities on students' attitudes toward statistics in an introductory statistics course. PhD Thesis, Old Dominion University.

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. Accessed Jan 2018

Cashin, S. E., & Elmore, P. B. (2005). The survey of attitudes toward statistics scale: A construct validity study. *Educational and Psychological Measurement, 65*(3), 509–524.

De Neys, W., Schaeken, W., & d'Ydewalle, G. (2005). Working memory and everyday conditional reasoning: Retrieval and inhibition of stored counterexamples. *Thinking & Reasoning, 11*(4), 349–381.

Elbulok-Charcape, M., Grandoit, E., Berman, L., Fogel, J., Fink, L., & Rabin, L. (2019). Improving exam performance in an undergraduate statistics course for at-risk students through peer tutoring. *Psychology Teaching Review, 25*(2), 3–17.

Evans, J. S. B. (2008). Dual-processing accounts of reasoning, judgment, and social cognition. *Annual Review of Psychology, 59*, 255–278. https://doi.org/10.1146/annurev.psych.59.103006.093629

Evans, J. S. B., & Stanovich, K. E. (2013). Dual-process theories of higher cognition: Advancing the debate. *Perspectives on Psychological Science, 8*(3), 223–241. https://doi.org/10.1177/1745691612460685

Garfield, J., & Ben-Zvi, D. (2007). How students learn statistics revisited: A current review of research on teaching and learning statistics. *International Statistical Review, 75*(3), 372–396.

Geary, D. C. (2007). *Educating the evolved mind: Conceptual foundations for an evolutionary educational psychology*. In J. S. Carlson, & J. R. Levin (Eds.), (pp. 1–99). Greenwich: Information Age.

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

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.

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). Cham, Switzerland: Springer International

Ginns, P., & King, V. (2021). Pointing and tracing enhance computer-based learning. *Educational Technology Research & Development, 69*, 1387–1403.

Glenberg, A. M., Goldberg, A. B., & Zhu, X. (2011). Improving early reading comprehension using embodied CAI. *Instructional Science, 39*(1), 27–39.

Gros, H., Thibaut, J. P., & Sander, E. (2020). Semantic congruence in arithmetic: A new conceptual model for word problem solving. *Educational Psychologist, 55*(2), 69–87.

Gros, H., Thibaut, J. P., & Sander, E. (2021). What we count dictates how we count: A tale of two encodings. *Cognition, 212*, 104665.

Guichemerre, C. (2011). *Enquête vie de campus*. Université de Bordeaux. http://www.cue-aquitaine.fr/docs/poleetudes/conditions_vie/tdb1.pdf

Kirschner, F., 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.

Lespiau, F. & Tricot, A. (2022). Primary vs. secondary knowledge contents in reasoning: motivated and efficient vs. overburdened. *Acta Psyhologica*. pp. 277

Lespiau, F., & Tricot, A. (2018). Primary knowledge enhances performance and motivation in reasoning. *Learning and Instruction, 56*, 10–19.

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.

Lespiau, F. (2017). Logique sans peine? Comment nous sommes plus performants et motivés pour raisonner logiquement à propos des connaissances primaires. Effortless logic? How we are better able and motivated to reason logically about primary knowledge. [Doctoral dissertation, Toulouse 2 Jean-Jaurès University]. DANTE.

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.

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.

Pennycook, G., Fugelsang, J. A., & Koehler, D. J. (2015). What makes us think? A three-stage dual-process model of analytic engagement. *Cognitive Psychology, 80*, 34–72.

Ping, R., & Goldin-Meadow, S. (2010). Gesturing saves cognitive resources when talking about non-present objects. *Cognitive Science, 34*(4), 602–619.

Popper, K. R. (1972). *Objective knowledge: An evolutionary approach*. Clarendon.

Popper, K. R. (1974). Intellectual autobiography. In P. A. Schillp (Ed.), *The philosophy of Karl Popper* (pp. 3–181). Open Court.

Popper, K. (1978). Natural selection and the emergence of mind. Dialectica, 32, 339–355.

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.

Sweller, J., van Merriënboer, J. J., & Paas, F. (2019). Cognitive architecture and instructional design: 20 years later. *Educational Psychology Review, 31*(2), 261–292.

Sweller, J. (2021). The Role of Evolutionary Psychology in our understanding of human cognition: Consequences for cognitive load theory and instructional procedures. *Educational Psychology Review*, 1–13.

Tricot, A., & Sweller, J. (2014). Domain-specific knowledge and why teaching generic skills does not work. *Educational Psychology Review, 26*(2), 265–283.

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.

Wang, B., Ginns, P., & Mockler, N. (2021). Sequencing tracing with imagination. *Educational Psychology Review*, 1–29.

Whittlesea, B. W., Jacoby, L. L., & Girard, K. (1990). Illusions of immediate memory: Evidence of an attributional basis for feelings of familiarity and perceptual quality. *Journal of Memory and Language, 29*(6), 716–732.

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.

Youssef-Shalala, A., Ayres, P., Schubert, C., & Sweller, J. (2014). Using a general problem-solving strategy to promote transfer. *Journal of Experimental Psychology: Applied, 20*(3), 215–231.