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Information without knowledge: the effects of Internet search on learning

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ABSTRACT

The Internet has radically shifted how people access information. Instead of storing information internally, increasingly, people outsource to the Internet and retrieve it when needed. While this is an efficient strategy in many ways, its downstream consequences remain largely unexplored. This research examines how accessing online information impacts how people remember information in a learning context. Across five experiments, participants studied for a quiz either by searching online to access relevant information or by directly receiving that same information without online search. Those who searched the Internet performed worse in the learning assessment, indicating that they stored less new knowledge in internal memory. However, participants who searched the Internet were as confident, or even more confident, that they had mastered the study material compared to those who did not search online. We argue that, by making information retrievability salient, Internet search reduces the likelihood of information being stored in memory. Further, these results suggest that searching online leads to the misattribution of online information to internal memory, thus masking the Internet-induced learning deficits.

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The world's knowledge is at our fingertips. The Internet has quickly become integrated into daily life: 81% of American adults now own smartphones, up from 35% in 2011 (Pew Research Center, 2019). Online tools provide an unprecedented amount of potential knowledge – English Wikipedia alone contains over 6 million articles (English Wikipedia, 2020). Information has never been more accessible, but are we taking full advantage of it?

People are unable to internally store all the information they need. To overcome this biological limitation, humans engage in cognitive offloading (Risko & Gilbert, 2016). The Internet has revolutionised the scale at which offloading can occur, allowing limitless information to be accessed at any moment. While this new technology creates many opportunities, our research explores the obstacles that prevent people from taking full advantage of them. Specifically, we find that Internet search can simultaneously induce learning deficits and prevent detection of these deficits.

Our research builds upon and contributes to two related streams of research on technology and memory. One stream focuses on how systematic reliance on external sources of information hinders the storage of that information in internal memory (e.g., Sparrow et al., 2011; Ward & Lynch, 2019). We propose that Internet search (i.e., Google) provides unequivocal cues of information availability and, as consequence, discourages storing new information in internal memory – even when learning is the explicit motivation of accessing that information in the first place. The second stream of research suggests that people conflate online information storage and retrieval with their own memory capacities (e.g., Fisher et al., 2015; Stone & Storm, 2021; Ward, 2013). We argue that because people do not accurately distinguish accessing information through Internet search from accessing information from internal memory, they think they mastered new knowledge, when in fact, they have not. We explore the intersection of cognitive and metacognitive consequences of the Internet across five experiments that emulate study preparation for formal knowledge assessments (e.g., school exams).

Cognitive consequences of Internet search

Humans improve their memory capacity by relying on external (human and non-human) memory resources in their environment (Wegner, 1987; Wegner et al., 1991). Commonplace external memory aids like lists, notebooks, and calendars are heavily relied upon for navigating our everyday lives (Block & Morwitz, 1999; Harris, 1980; Intons-Peterson & Fournier, 1986). Knowledge can also be distributed across a social network, giving rise to interconnected knowledge systems with human memory partners. As people coordinate the distribution of relevant

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information with these external memory resources, they form information systems known as transactive memory (Wegner, 1987). In these systems, it is less critical to store information in one's own memory, as long as it can be easily retrieved from its external location when needed. However, transactive memory systems also entail a sensitivity to cues of external information retrievability. When information can reliably be found elsewhere, internal memory storage becomes redundant and no longer necessary (Hu et al., 2019; Sparrow et al., 2011; Ward & Lynch, 2019; Wegner et al., 1991; Weis & Wiese, 2019). This distribution of memory does not need to be explicitly negotiated; it often arises as an implicit structure formed through experience (Wegner et al., 1991). Collectively, this process improves efficiency – cognitive specialisation enhances the overall performance of the group. Individually, however, it can hinder the capacity of members of the system to learn about and perform in areas outside their specialty. For example, relationship partners complement each other in a transactive memory system by becoming responsible for different domains of knowledge (e.g., household finances, cooking, etc.); but this distribution of cognitive responsibility impairs each partner's capacity to learn about topics in the others' domain (e.g., Ward & Lynch, 2019).

In recent years, the Internet has become a primary tool for learning about the world; among many other uses, it is commonly used to research medical issues, learn about government, or acquire educational materials (Smith & Page, 2015). Tools like Google search make external information accessible at any time, from almost any physical location, and with little effort. When information saved in computer folders can be accessed later, people are less likely to remember it themselves (Sparrow et al., 2011). Thus, we argue that accessing information online (a reliable external source) cues outsourcing, signalling to the user that internal storage is not necessary. As a result, information accessed through Internet search (vs. without Internet search) is less likely to be stored in internal memory.

Metacognitive consequences of Internet search

People often face difficulties in recognising the best practices for learning effectively. A large literature on self-regulated learning suggests that, independent of technology's effects, people often make misguided inferences regarding the efficiency of learning methods (Bjork et al., 2013; Kornell, 2009; Kornell et al., 2011; Undorf & Zimdahl, 2019). We argue that, in addition to impairing information storage in memory, Internet search presents an additional challenge: it masks how much is actually being stored internally.

A growing body of work suggests that metacognitive processes can fail to recognise the Internet as an external resource when people use online search engines (e.g, Chabris & Simons, 2010; Fisher et al., 2015; Stone & Storm, 2021; Ward, 2013). For example, searching for explanatory knowledge online inflates people's assessments of their own capacity to provide answers for topics unrelated to the original search (Fisher et al., 2015). Internet search also induces the misattribution of factual information found online to one's own memory and boosts cognitive self-esteem (Ward, 2013). Further, people confound the fluency with which they access online information with the ease with which they can themselves recall information (Stone & Storm, 2021). In sum, the cues that metacognition typically uses to detect the presence of an external source – e.g., the time and effort involved in retrieving information from them – are made less clear when people engage in Internet search. As a consequence, Internet search makes it more difficult to accurately identify where information is stored – internal versus external (online) memory. Thus, while searching online, people may fail to recognise the extent to which their memory is offloaded and may remain unaware of their own Internet-induced learning deficits.

Overview of experiments

Across five experiments, participants read about a topic and then completed an assessment to measure how much they learned. These experiments examined the predictions that (1) online search reduces the storage of new information and (2) people remain unaware of Internet-induced learning deficits. Experiment 1 presents a straightforward test of these predictions and establishes the paradigm on which we build the subsequent experiments. Experiment 2 replicates Experiment 1 while accounting for the fact that those who search online face additional distractions. Experiments 3a and 3b examine if Internet-induced boosts in confidence explain the performance deficits by reducing effort to learn. Despite inducing equal study time for participants who search and those who do not, both experiments show that the differences in learning outcomes persist. Lastly, Experiment 4 compares following a direct link and searching Google to access the same website and provides evidence for the importance of retrievability cues. Across all studies, accessing the same study material through online search led to poorer performances on the knowledge assessments, but participants who searched the study material online were at least as confident in their knowledge as those who did not access it through online search – in some cases, significantly more confident. The performance gap does not seem to be explained by factors such as reduced engagement, search-related distractions, premature cessation of the learning phase due to Internet-induced overconfidence, or factors related to the websites of the study materials. Instead, we argue that when people see how to reliably access new information using Google, they become less likely to store that information in their own memory.

Experiment 1

Experiment 1 presents a straightforward test of the predictions that when people search for information online to prepare for a learning assessment, they will recall less of the material as assessed by a follow-up quiz and will not display an awareness that less knowledge was stored during the preparation for the assessment.

Method

Participants

One hundred ninety-nine participants (113 males, 86 females, $M_{Age} = 34.00$, $SD = 9.41$, $M_{Education} = 4.23$, $SD = 1.25$[1]) from the United States completed the study through Amazon Mechanical Turk (Bohannon, 2016; Litman & Robinson, 2020). Sample size was based on results using a comparable paradigm (Fisher et al., 2015) and pilot testing. Once the requested number of participants completed each experiment, data collection ended. Each study contained a unique naive sample.

Procedure and design

All participants were instructed that they would have the opportunity to learn about a topic before completing a quiz without using any outside resources. Participants were incentivized to learn the material – before the learning phase of the study (Phase 1), they were informed they could earn a bonus payment based on their performance on the quiz (See Appendix A for exact instructions). Each participant was randomly assigned to learn about one of the following three topics: inflation (economics), photosynthesis, or autism. These topics were selected for generalizability (each topic represents a different discipline) and depth (each topic decomposes into multiple sub-topics). In Phase 1, participants studied for the quiz by viewing three sources of information related to the main topic (see Appendix B). Participants could spend as much time on each subtopic as they needed.

Participants were randomly assigned to one of two conditions: Internet Search (56% male, $M_{Age} = 33.67$, $M_{Education} = 4.42$) or No Internet Search (58% male, $M_{Age} = 34.12$, $M_{Education} = 4.09$). The Internet Search condition was instructed to search for information from a specific website to learn more about the sub-topics. For example, participants would receive the following instruction, "Topic: Autism Treatment Options. Please search online for the apa.org page with the text about this topic to confirm details about it" and were reminded that the quiz questions would be based on the information from the website. Participants would then search for and read the article. They were then asked to copy and paste the URL from the website they accessed so we could verify that they found the correct website. Participants in the Internet Search condition correctly followed the experimental instructions – on average, they reported back the correct URL for 2.93 of the 3 articles ($SD = .26$). Participants who did not correctly report the 3 URLs were excluded from all analyses. There are no significant changes in the results for this experiment (or later experiments) if participants who reported at least one incorrect URL are included in the analysis.

The No Internet Search condition viewed the same material about the same sub-topics, but read the text within the survey, without ever engaging in online search. The passages were taken directly from the websites that the participants in the Internet Search condition were instructed to view so that the content was identical across the two conditions. In the No Internet Search condition, participants were instructed to: "Please confirm details about this topic with the text below, taken from [domain name]" and were reminded that the quiz questions would be based on that information. For both conditions, time spent studying each sub-topic provided a measure of engagement in the learning process.

In Phase 2, once participants finished studying for the quiz, we evaluated participants' confidence in their ability to answer questions about the topic, followed by actually assessing their knowledge using a multiple-choice quiz. They were asked, "What percentage of multiple-choice questions on this topic do you think that you will answer correctly?" and responded on 0–100 sliding scale. This was to assess whether Internet Search participants were aware of their (hypothesised) learning deficits. Then, instructions for the quiz informed participants there would be six questions (See Appendix C), with a maximum of 15 s allotted per question. The time pressure was introduced to prevent participants from looking up the answers to questions in order to earn the bonus payment (even though they were specifically instructed not to use outside resources). The six questions for the assigned topic were presented to participants in a random order. To avoid floor effects and make quiz scores as objective as possible, all questions were multiple choice. The quiz consisted of two questions from each of the three articles from the learning phase. See Figure 1 for a flowchart of Experiment 1's procedure – which also serves as a foundation for the subsequent studies.

Data availability

De-identified raw data files, analytic syntax, and preregistration information are available at Open Science Framework (https://osf.io/zk2tf/).

Results

In line with our hypotheses, participants in the Internet Search condition answered significantly fewer quiz questions correctly ($M = 49.33\%$, $SD = 25.47\%$, 95% CI = [43.47%, 55.19%]) than participants in the No Internet Search condition ($M = 62.29\%$, $SD = 29.03\%$, 95% CI = [57.00%, 67.58%]), $t(191) = -3.17$, $p = .002$, Cohen's $d = -0.47$. Furthermore, participants in the Internet Search

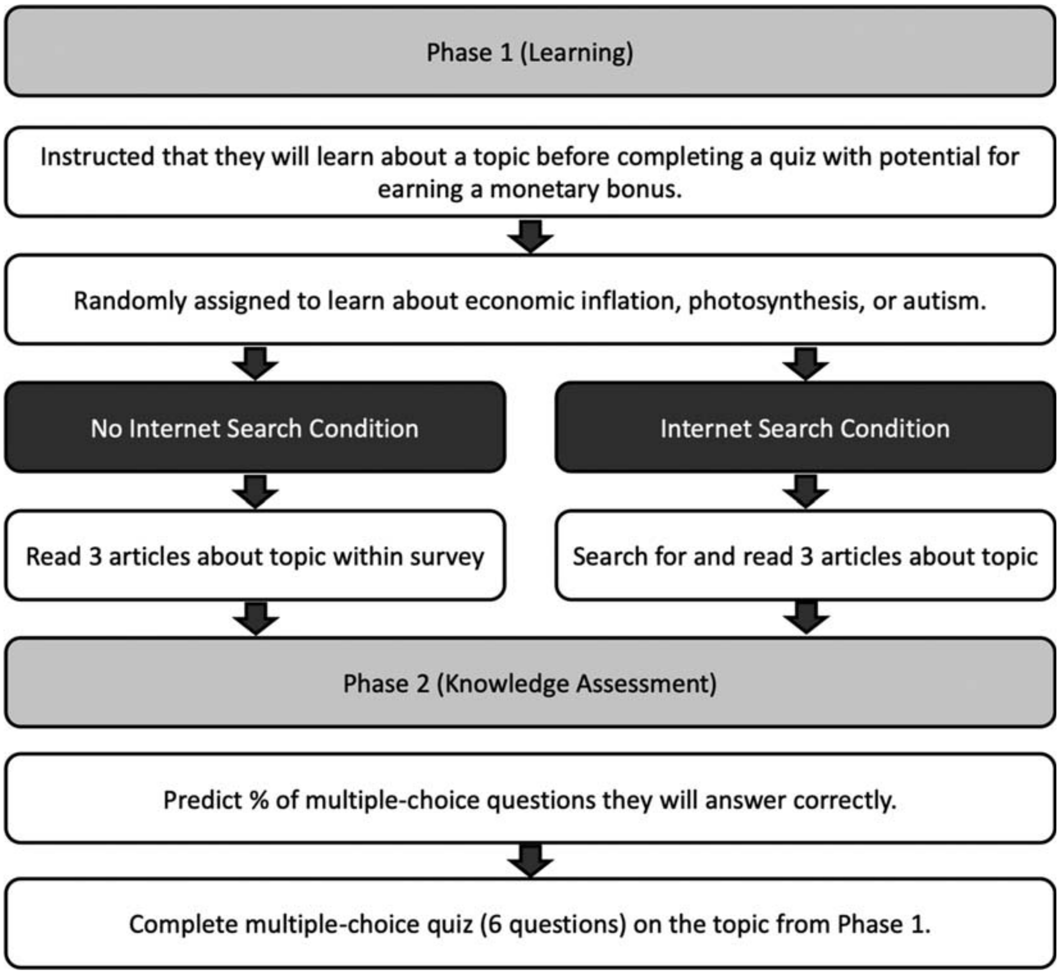

Figure 1. Procedure for both conditions in Experiment 1.

condition were unaware of how searching would affect their performance: they predicted that they would score better on the quiz ($M = 66.87\%$, $SD = 21.36\%$, 95% CI = [61.95%, 71.78%]) than those in the No Internet Search Condition ($M = 58.53\%$, $SD = 25.79\%$, 95% CI = [53.82%, 63.23%]), $t(191) = 2.34$, $p = .02$, Cohen's $d = 0.35$ (all p-values correspond to two-sided tests), see Table 1. These results, broken down by topic, are displayed in Table 2.

Participants in the Internet Search condition spent significantly less time (in seconds) in the learning phase ($M = 226.44$, $SD = 176.19$) than those in the No Internet Search condition ($M = 360.03$, $SD = 349.44$), $t(191) = -3.07$, $p = .002$, Cohen's $d = -0.45$. This result indicates another consequence of online search, namely, a reduction of study time. The potential issue of study time explaining the differences in quiz scores is addressed directly in Experiments 3a and 3b.

The Internet Search condition inconvenienced participants more than the No Internet Search condition, since it required navigating away from the main survey and using a different tab on the browser to search for answers. Indeed, we observed that participants in the Internet Search condition were more likely to drop-out of the survey compared to those in the No Internet Search condition. Despite random assignment to condition, the sample (prior to excluding those who failed the search task) included more participants in the No Internet Search ($N = 118$) condition than the Internet Search condition ($N = 81$). However, it seems unlikely that the difference in drop-out rates may have induced a selection effect that explains our results. To the extent that Internet search was perceived as an inconvenient task to complete as part of a study, the Internet Search condition may have selected participants who were generally more engaged with the study task than participants in the No Internet Search condition. That is, those who did not want to put

Table 1. Mean (Standard Deviation) for all experiments.

	Prediction		Performance	
Topic	Internet Search	No Internet Search	Internet Search	No Internet Search
Experiment 1	67% (21%)	59% (26%)	49% (25%)	62% (29%)
Experiment 2	68% (21%)	65% (20%)	54% (27%)	68% (26%)
Experiment 3a	60% (25%)	64% (24%)	47% (29%)	66% (26%)
Experiment 3b	71% (18%)	63% (22%)	54% (26%)	63% (30%)
Experiment 4	64% (25%)	66% (23%)	50% (25%)	59% (29%)

Table 2. Mean (Standard Deviation) for main results by topic in Experiment 1.

	Prediction		Performance	
Topic	Internet Search	No Internet Search	Internet Search	No Internet Search
Autism	63% (18%)	67% (21%)	59% (24%)	83% (22%)
Inflation	68% (19%)	56% (26%)	49% (27%)	54% (29%)
Photosynthesis	70% (26%)	53% (28%)	40% (22%)	50% (25%)

forth the effort to look up online articles dropped out of the Internet Search condition, leaving only those who with higher levels of engagement. Increased engagement in the Internet Search condition should lead to better performance on the quiz, but that is the opposite of what we found. Thus, if anything, the differential drop-out rate provides a conservative test for our hypothesis and could mean that our results underestimate the negative influence of online search on information retention.

Experiment 2

Experiment 2 served three main purposes. First, in Experiment 1, the Internet search task may have introduced distractions that affected the learning outcomes in the Internet Search condition. Specifically, while No Internet Search participants could focus on the content of the study material as soon as they received their sub-topics, Internet Search participants had to move to a different tab, type in the search terms, and identify the correct source before they were able to focus on the study material. As a more stringent test of our predictions, in Experiment 2, participants in the No Internet Search condition performed two distractor tasks that were comparable in duration and difficulty to the tasks involved in using an online search engine. Second, to provide converging evidence for miscalibrated metacognition in the Internet Search condition, participants in Experiment 2 reported confidence in their newly acquired knowledge instead of predicting performance. Third, Experiment 2 aimed to replicate the set of findings reported in Experiment 1.

Method

Participants

One hundred ninety-six participants (103 males, 93 females, $M_{Age} = 35.56$, $SD = 12.01$, $M_{Education} = 4.10$, $SD = 1.20$) from the United States completed the study through Amazon Mechanical Turk.

Procedure and design

In Phase 1, participants in the No Internet Search condition ($N = 111$, 54% male, $M_{Age} = 35.20$, $M_{Education} = 4.08$) performed two additional tasks before viewing the article for each sub-topic. The first task was to write the sub-topic in their own words ("Please put the phrase "How do you calculate the inflation rate?" into your own words below:"). This task was intended to mimic entering a query into a search bar. The second task was to complete a CAPTCHA that required individuals to recognise alphanumeric characters in a visually noisy image and type them into a box. This task aimed to match the effort required by those in the Internet Search condition ($N = 85$, 51% male, $M_{Age} = 35.90$, $M_{Education} = 4.15$) to scan through search results and recognise the target link. While the No Internet Search condition added these additional tasks, the Internet Search condition remained identical to Experiment 1. Participants in the Internet Search condition again reported the websites they used to study and found the correct URL for $M = 2.93$ ($SD = .26$) of 3 sub-topics.

As a converging measure of confidence, once participants completed Phase 1, they were asked, "How confident are you in your ability to answer questions about the topic?" on a 1 (*not at all confident*) to 7 (*very confident*) Likert scale. Otherwise, Experiment 2 was identical to Experiment 1.

Results

Participants in the Internet Search condition again answered significantly fewer questions correctly on the quiz ($M = 53.59\%$, $SD = 24.27\%$, 95% CI = [48.15%, 59.02%]) than participants in the No Internet Search condition ($M = 67.57\%$, $SD = 26.38\%$, 95% CI = [62.60%, 72.53]), $t(188) = -3.72$, $p < .001$, Cohen's $d = -0.55$. Despite this difference in performance, participants across conditions reported equal levels of confidence before the quiz, $M_{Internet\ Search} = 4.73$, $SD_{Internet\ Search} = 1.49$, 95% CI = [4.40, 5.07]; $M_{No\ Internet\ Search} = 4.53$, $SD_{No\ Internet\ Search} = 1.37$, 95% CI = [4.27, 4.79], $t(188) = .97$, $p = .33$. Even though the No Internet Search condition completed additional distractor tasks in Experiment 2, the Internet Search condition still spent significantly less time in the learning phase ($M = 262.70$, $SD = 212.67$) than those in the No Internet Search condition ($M = 436.38$, $SD = 322.84$), $t(188) = -4.18$, $p < .001$, Cohen's $d = -0.61$.

Experiment 3a

In the previous experiments, Internet search not only led to worse performance accompanied by miscalibrated confidence, it also decreased study time. The difference in study time could be driving, or at least partially explaining, differences in performance. Less studying could lead to worse quiz scores. While the effect on study time is a noteworthy independent finding, based on the theory underlying our predictions, Internet search should decrease quiz accuracy even when study time is held constant. Our predictions build on the notion that, when using Google, people encode the steps to retrieve information online instead of the information itself (Sparrow et al., 2011). This tendency should not change if people take more time or put more effort into processing the information, since it is driven by the accessibility cues.

We find preliminary support for our rationale in additional analyses of our previous experiments: when study time is entered as a control variable in a linear regression model, the effect of the experimental condition on prediction error remains significant in Experiment 1 and 2 (see online analytic syntax). Experiments 3a and 3b address this issue more directly. Experiment 3a introduced a time constraint in the learning phase so that participants studied for the same amount of time across conditions. We predicted that even with time held constant, those in the Internet Search condition would process the information differently: after experiencing information accessibility via Google search, they will be less likely to store the information internally.

Method

Participants

Two hundred participants (115 males, 85 females, $M_{\text{Age}} = 34.70$, $SD = 10.26$, $M_{\text{Education}} = 4.16$, $SD = 1.45$) from the United States completed the study through Amazon Mechanical Turk. Because of the audio feature used for the timers in Experiment 3a, only those who had functioning sound on their device were eligible to participate.

Procedure and design

Experiment 3a made several minor changes to the paradigm used in the previous experiments. As before, participants were randomly assigned to search for particular articles online (Internet Search condition; $N = 90$, 53% male, $M_{\text{Age}} = 34.23$, $M_{\text{Education}} = 4.10$) or be presented those same articles within the survey (No Internet Search condition; $N = 110$, 61% male, $M_{\text{Age}} = 35.08$, $M_{\text{Education}} = 4.21$). At the start of Phase 1, all participants in Experiment 3a were instructed that they would have a limited amount of time to study the 3 articles before taking the quiz. Using the data from the previous experiments, we determined the average amount of time participants spent reading each of the articles and used that as each sub-topic's time limit in Experiment 3a. When each topic was presented, a timer at the top of the display would begin counting down the amount of time remaining. The amount of time per sub-topic ranged from 61 s to 195 s, depending on the length of the article. Participants could not continue until the timer expired, but once it did, the survey auto-advanced to the next page. Though study time varied by topic, the total amount of study time was held constant between the two groups since participants read the same articles on the same topics in both conditions. Based on pilot testing, we determined that participants in the Internet Search condition spent an average of 10 s finding the assigned article. To most closely match study time, 10 s were added to the allotted time for each sub-topic in the Internet Search condition. Since participants in the Internet Search condition click away from the survey to search for the articles, they needed to be alerted that their time had expired. To do so, an alarm sounded when three seconds remained on the timer. The same alarm was also used in the No Internet Search condition in order match the two experimental conditions as closely as possible. To make sure the alarm would be audible, all participants were told at the beginning of the study that an alarm would sound when three seconds remained and were instructed to adjust their volume appropriately. Because of the auto-advancing, participants in the Internet Search condition no longer reported the URL of the websites they found during the learning phase. Instead, after completing the quiz, participants were shown the 3 URLs they were instructed to find and were asked "Did you view all three of the pages below during the learning phase?" (90% responded Yes).

Phase 2 of Experiment 3a was the same as in Experiment 2, with participants reporting confidence in their ability to answer questions about the topic before taking the quiz. Unlike Experiment 2, the distractor tasks for the No Internet Search condition were not used.

Results

Despite spending the same amount of time reading the articles, participants in the Internet Search condition again scored worse on the quiz ($M = 46.67\%$, $SD = 28.94\%$, 95% CI = [40.60%, 52.73%]) than participants in the No Internet Search condition ($M = 65.76\%$, $SD = 25.63\%$, 95% CI = [60.92%, 70.60%]), $t(198) = -4.94$, $p < .001$, Cohen's $d = -0.70$. Participants in the two conditions did not significantly differ in their levels of confidence before the quiz, $M_{\textit{Internet Search}} = 4.18$, $SD_{\textit{Internet Search}} = 1.73$, 95% CI = [3.82, 4.54]; $M_{\textit{No Internet Search}} = 4.50$, $SD_{\textit{No Internet Search}} = 1.65$, 95% CI = [4.19, 4.81], $t(198) = -1.34$, $p = .18$. These results indicate that our findings in the earlier experiments were not driven solely by additional study time. When controlling for time, Internet search led to worse performance even though participants in both conditions did not differ meaningfully in their confidence levels, indicating an Internet-induced change in the type of processing and encoding capacities, not in the amount of processing. These findings support the key theoretical notion that accessible information is not encoded and stored to the same degree as information that will not be easily retrievable in the future.

Experiment 3b

Whereas Experiment 3a forced participants to study a certain amount of time, Experiment 3b equated study time in a different way. During Phase 1 of Experiment 3b, participants were prompted to pause and reflect on their own knowledge before advancing from each sub-topic. A short reflection of one's explanatory abilities (REA) can counteract intellectual overconfidence to nearly the same degree as attempting to generate a full explanation (Johnson et al., 2016). Simply pausing to reflect on one's own ability to explain the details of a phenomenon helps identify knowledge gaps, potentially recalibrating self-assessments of knowledge. Thus, REA should prevent Internet Search participants from exiting the learning phase too early and could potentially lead to better calibrated predictions of actual performance on the knowledge assessment. With this in mind, Experiment 3b explored whether a REA intervention in the learning phase could equate study time and perhaps improve knowledge calibration and performance for those searching the Internet.

Method

Participants

Two hundred participants (104 males, 96 females, M_{Age} = 35.78, SD = 11.60, $M_{Education}$ = 4.24, SD = 1.34) from the United States completed the study through Amazon Mechanical Turk.

Procedure and design

Experiment 3b used the same procedure and measures as Experiment 2, except that no distractor tasks were included in the No Internet Search condition (N = 119, 45% male, M_{Age} = 37.12, $M_{Education}$ = 4.13) and, most importantly, before advancing to each subsequent sub-topic in Phase 1, participants in both conditions received the following instructions: "carefully reflect on your ability to explain to an expert, in a step-by-step, causally-connected manner, with no gaps in your story [current sub-topic]" (Johnson et al., 2016). Participants could then continue to study the sub-topic for as long as they desired or advance to the next article. In the Internet Search condition (N = 81, 59% male, M_{Age} = 34.00, $M_{Education}$ = 4.43), participants reported using the correct URL for 2.93 of the 3 articles on average (SD = .35).

Results

As expected, the Internet Search condition spent as much time in the learning phase (M = 399.74, SD = 280.42) as the No Internet Search condition (M = 363.65, SD = 271.32), t(194) = .90, p = .37. Thus, the REA instructions succeeded in matching study times across conditions. Like the previous experiments, the Internet Search group performed worse on the quiz (M = 53.68%, SD = 26.16%, 95% CI = [47.74%, 59.62%]) than the No Internet Search group (M = 63.31%, SD = 29.95%, 95% CI = [57.87%, 68.74%]), t(194) = −2.31, p = .02, Cohen's d = −0.34. However, participants in the Internet Search condition felt more confident before taking the quiz (M = 4.94, SD = 1.27, 95% CI = [4.65, 5.22]) compared to participants in the No Internet Search condition (M = 4.39, SD = 1.55, 95% CI = [4.12, 4.67]), t(194) = 2.60, p = .01, Cohen's d = 0.38.

Experiment 3b further indicates that the negative effect of Internet search on learning outcomes are not simply explained by reduced effort during the learning process. In fact, both the inferior performance and displays of unawareness of the learning deficit persisted among participants who accessed study materials through Internet search despite Experiment 3b's encouragement to reflect on one's explanatory capacity. Importantly, this encouragement equated study time across conditions, suggesting that processing effort was similar, independently of how participants accessed the study materials.

Experiment 4

Experiment 4 was designed to rule out alternative explanations and help pinpoint the psychological processes driving the effect. During Phase 1 in Experiment 4, all participants navigated away from the survey to access the same study materials. They did so by either searching online (as in the Internet Search condition of the previous studies) or by clicking a link that took them directly to the webpage (instead of reading the study material on a page embedded in the survey, which was the case in our previous studies). Thus, in Experiment 4's Internet Search condition, the retrievability of the study material was highlighted – the process of online search made it salient that information can easily be found on Google with the search terms that were used to access it in the first place. In turn, in the new Link condition, simply accessing the webpages by clicking a link does not highlight how that information could be found again in the future (e.g., which search terms to use, where it would be in the list of search results). Compared to our previous No Internet Search conditions, accessing the study material via the link may provide additional information about where the study material is stored, since participants interact with the source directly. However, without reaching the website through Internet search, participants remain unexposed to cues of how easy it would be for them to find the same source in the future.

Moreover, an alternative account for the findings of our previous experiments is that participants in the Internet Search condition opened the study materials in separate browser tabs and planned to refer back to them during the quiz. Thus, they predicted higher (or equivalent) performance, but in fact, did worse than participants in the No Internet Search condition on the time-pressured quiz. Study 4 also helps rule out this possibility by equating these dynamics across conditions – having study materials opened on different tabs during the quiz was possible in both experimental conditions.

Method

Participants

Four hundred one participants (226 males, 175 females, M_{Age} = 36.17, SD = 11.43, $M_{Education}$ = 4.14, SD = 1.34) from the United States completed the study through Amazon Mechanical Turk. Sample size was determined using an estimated effect size from a pilot study (Power = .90).

Procedure and design

Experiment 4 was formally preregistered (https://osf.io/3wbc9) and the reported design and analyses did not deviate from that plan. In Experiment 4, participants were randomly assigned to either the Internet Search ($N = 171$, 54% male, $M_{Age} = 34.50$, $M_{Education} = 4.09$) or the Link condition ($N = 230$, 56% male, $M_{Age} = 36.97$, $M_{Education} = 4.09$). The Internet Search condition was identical to the Internet Search condition from Experiment 1 and 2. In the Link condition, during Phase 1 of the study, participants were presented with each sub-topic (e.g., Does inflation favour lenders or borrowers) and then asked to "confirm details about this topic by clicking the link below." Like the Internet Search condition, for each sub-topic, participants were told, "Reminder, the questions on the quiz will be based on the information from this website." Below this text was a blue hyperlink labelled "link", which when clicked, opened a new tab and directed participants to the same website accessed by participants in the Search condition. Thus, all participants had the study material available to them in a same way. Only the way in which those materials were accessed varied by condition. Participants in the Internet Search condition correctly reported the URL for, on average, 2.79 of the 3 articles ($SD = .61$).

In Phase 2, all participants were asked, "What percentage of multiple-choice questions on this topic do you think that you will answer correctly?" [0–100]. All participants then complete the same quiz from the previous experiments.

Results

Participants in the Internet Search condition performed significantly worse on the quiz ($M = 50.00\%$, $SD = 25.12\%$, 95% CI = [45.92%, 54.08%]) than those in the Link condition ($M = 59.49\%$, $SD = 28.90\%$, 95% CI = [55.74%, 63.25%]), $t(376) = 3.23$, $p = .001$, Cohen's $d = .35$. Despite the worse performance, participants in the Internet Search condition did not significantly differ in their predicted quiz performance ($M = 63.68\%$, $SD = 25.20$, 95% CI = [59.58%, 67.77%]) from those in the Link condition ($M = 65.68\%$, $SD = 23.28\%$, 95% CI = [62.65%, 68.70%]), $t(376)$, $p = .42$.[2] Corroborating the results from Experiment 3, study time does not appear to explain the differences across conditions. Those in the Internet Search condition spent non-significantly longer in the learning phase of the study ($M = 239.92$ s, $SD = 177.71$) than those in the Link condition ($M = 208.60$ s, $SD = 234.23$), $t(376) = -1.39$, $p = .17$, yet still performed worse on the quiz. Thus, Experiment 4 replicated the pattern of results from the previous studies. When participants accessed the information through Internet search, they performed worse on the quiz compared to those who accessed the exact same information through a link, yet they did not accurately predict lower performance.

General discussion

The current research makes several contributions. First, we show that beyond using folders on a computer (Sparrow et al., 2011), using Internet search to learn new information leads people to be less likely to store information internally. Secondly, it expands the understanding of the illusion of knowledge induced by retrieving information online (Fisher et al., 2015; Ward, 2013). By simultaneously exploring cognitive and metacognitive effects, we show that those who learn via online search perform worse on the learning assessments, yet also remain unaware of their learning deficit. Third, we explore the underlying cues that lead to these differences. Because online search inflates confidence, one might suspect that online search diminishes effort to learn (i.e., the feeling of knowing makes people assume that additional studying is unnecessary). This decrease in engagement would then lead to poorer performance on the assessment. Experiments 1 and 2 show that online search reduces study time, which suggests reduced processing effort. However, Experiments 3a, 3b, and 4 indicate that this is not the only factor hindering learning and suggest that online search induces changes in the processing of new information. Since Internet search cues accessibility, it is likely to decrease how much information is encoded and stored in internal memory, thus helping explain why participants who studied online performed worse when tested.

Previous research on the Internet's effect on learning processes has largely focused on the ways the Internet can be a distraction (e.g., Feng et al., 2019; Karpinski et al., 2013). Even in other contexts, cognitive performance is hindered by demands on working memory (Kalaman & Lefevre, 2007). Our research sheds light on the effects of the Internet above and beyond its function as a distraction. In our experimental task, (as in real world) distracting elements were inherent to online learning. Internet search itself (i.e., opening Google, typing into the search box, and scrolling through the results page) could be a distraction, but that does not fully explain the difference in learning outcomes (see Experiment 2). In addition, when people read information from a website they must also contend with a host of distractions like advertisements, links, images, etc. While the articles used in our studies were selected to minimise these elements, could such features of online learning still explain our results? If participants were substantially more distracted in the Internet condition, two possible patterns of results would be expected. First, participants could compensate for the distracting learning environment by spending additional time studying the material. In fact, the results show the opposite pattern: study time was either lower or not significantly different when people searched online. Second, participants could terminate the learning session early due to the additional cognitive load (i.e., fatigue), in which case they should report lower confidence in how much of the material they had learned because they were aware that the distractions were undermining their learning. However, we find that participants who used Internet search were at least as confident in their knowledge of the material as those who did not use online search, reporting significantly *more* confidence in their knowledge of the material in two experiments (1 and 3b). Our explanation based on accessibility cues and metacognitive errors, but not a distraction account, can explain both patterns of results: less study time and unwarranted confidence in one's own knowledge. Furthermore, in Experiment 4, where the distracting elements on the assigned websites were identical across conditions, participants still overestimated their knowledge more after searching the Internet.

While the current research identified a negative consequence of online search, offloading information can be beneficial in many ways. For instance, by outsourcing information that is trivially easy to retrieve, people can use their cognitive resources in other ways (Storm & Stone, 2015). In this vein, Sparrow and Chatman (2013) suggested that online information retrieval might lead to boosts in sense of control, which bolsters critical thinking. Our reliance on new technologies may not only have cognitive benefits, but social benefits as well (Mourey et al., 2017). Further, since the Internet has the capacity to boost self-confidence, studying online might stimulate students to focus on material related to the studied topic outside the formal learning process.

Future directions

The unique combination of features of accessing online information may make the Internet stand out from other available memory outsourcing strategies. People have historically outsourced knowledge to human memory partners and physical objects (i.e., diary, calendar), which can be more easily distinguished from one's own mind than the Internet. The absence of common cues of the external memory, such as the voice of the memory partner or the physical and mental effort involved in querying external sources, makes it difficult to determine what has and has not already been stored in internal memory. Importantly, access to external information is becoming increasingly effortless and ubiquitous, not only through computers and laptops, but also through smartphones and digital assistants (e.g., Amazon Alexa, Google Nest). As this new, connected environment continues to develop, it is important to more fully understand its cognitive and metacognitive consequences. Future research could explore the individual-level variables that predict the phenomena explored in the current studies. For example, those who rely on intuition seem to be more reliant on smartphones for providing them information in their daily lives (Barr et al., 2015), which could make them especially suspectable to learning deficits. Furthermore, using online search leads to more frequent searching in the future (Storm et al., 2016), suggesting that those that spend more time on the Internet may show stronger effects on learning.

The consequences explored in the current studies could be especially pronounced when using online search but could be also present in other contexts. People report being more knowledgeable about a scientific phenomenon when they learn scientists understand it (Sloman & Rabb, 2016), suggesting that communities of knowledge, not just the Internet, can induce illusions of knowledge. Additionally, when solving anagrams, participants spend less time looking for the solution when they know the answer will be made available afterwards (Risko et al., 2017) and the availability of outside hints leads to overconfidence (Fisher & Oppenheimer, in press). More fundamentally, easily accessible information can impair learning and this remains an important avenue for future research.

Popular critics have made the case that the Internet leads to cognitive laziness (Carr, 2008; Spitzer, 2012). However, the current studies suggest that the Internet has effects on memory and metacognitive processing that have little to do with "laziness" per se. These effects do not reflect a fundamental deficiency, but rather potentially maladaptive responses to an otherwise efficient transactive memory system. Thus, future research could explore ways to make online learning as effective as possible. There are several promising strategies that could help prevent performance deficits produced by new technologies. The first involves the immediacy of information access. In an online learning context, answers found quickly online were incorrectly judged more likely to be remembered (Stone & Storm, 2021). Additionally, when outside assistance is delayed or actively chosen, people show improved metacognitive calibration (Fisher & Oppenheimer, in press). Perhaps implementing deliberate delays could help people better track their learning. Second, elevated internal state awareness (i.e., one's attention to one's own feelings, sensations, and changes in mood) can neutralise prime-to-behavior effects (Wheeler et al., 2008). Perhaps a basic awareness of the metacognitive effects of the Internet may encourage encoding and storing new information and the use of complementary learning methods that counteract the learning deficits identified in these studies. Third, taking the time to explicitly test long-term memory can increase metacognitive accuracy (Dunlosky & Nelson, 1992; Nelson & Dunlosky, 1991) and may be a useful strategy to identify how much one knows without depending on any external resources. Lastly, some types of online learning may not have a negative impact on learning. For example, if accessibility cues drive the results observed in the current studies, then when information is difficult to find or hard to retrieve (e.g., password protected), it may be more likely to be remembered.

Conclusion

Although the current studies highlight potential drawbacks of using the Internet to access information that would otherwise require considerably greater effort to be reached, the Internet can still be a tremendously useful learning tool. The growing body of work examining how technology affects cognitive processes can help people take full advantage of the possibilities that the Internet and related technologies offer while avoiding the potential shortcomings.

Notes

1. For all studies, the following question assessed participants level of education: "What is the highest level of education you have completed?" 1 = Less than High School, 2 = High School / GED, 3 = Some College, 4 = 2-year College Degree, 5 = 4-year College Degree, 6 = Master's Degree, 7 = Doctoral Degree, 8 = Professional Degree (JD, MD).
2. The preregistered analysis plan included one-tailed independent sample t-tests. Since two-tailed tests did not change the significance of any results, they are reported here.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendices

Appendix A

Instructions

Internet condition

You will next be presented opportunities to learn different components about a particular topic. You will be provided with instructions for where to find the relevant information online for each topic which will help you prepare for the exit quiz. You can earn a bonus based on your performance on the quiz, if you score 80% or higher. Questions on the quiz will be based only on information from the designated webpages. Please do not use any outside sources other than the ones provided.

No Internet condition

You will next be presented opportunities to learn different components about a particular topic. You will be provided relevant information for each topic which will help you prepare for the exit quiz. You can earn a bonus based on your performance on the quiz, if you score 80% or higher. Questions on the quiz will be based only on information in the readings. Please do not use any outside sources.

Appendix B

Topics

Photosynthesis

1. How are plants so efficient? (http://www.economist.com/blogs/economist-explains/2014/12/economist-explains-1)
2. Discovery of Photosynthesis (http://photosynthesiseducation.com/discovery-of-photosynthesis/)
3. Light and Dark Reactions in Photosynthesis (https://www.wyzant.com/resources/lessons/science/biology/photosynthesis/light-dark-reactions)

Inflation

1. How do you calculate the inflation rate? (http://www.rateinflation.com/inflation-information/calculate-inflation)
2. Who benefits from inflation? (http://www.investopedia.com/ask/answers/111414/does-inflation-favor-lenders-or-borrowers.asp)
3. What are some causes of inflation? (http://www.frbsf.org/education/publications/doctor-econ/2002/october/inflation-factors-rise/)

Autism

1. Autism Treatment Options (http://apa.org/topics/autism/treatment.aspx)
2. Five Autism Types Explained (http://www.iser.com/resources/autism-types.html)
3. Causes of Autism (http://www.autism-society.org/what-is/causes/)

Appendix C

Quiz questions

Photosynthesis quiz questions

Q: How efficient are plants during the first stage of photosynthesis?

○ 90% (1)
○ 10% (2)
○ 45% (3)
○ 65% (4)

Q: What is an electron-ion pair known as?

○ Exciton (1)
○ Chlophyl (2)
○ Algae (3)
○ Solar Energy (4)

Q: Who proved that water was important to plant growth?

○ Jan Baptista van Helmont (1)
○ Gregor Mendel (2)
○ Joseph Priestely (3)
○ Sir Isaac Newton (4)

Q: What did Julius Robert Mayer propose about plants?

○ Plants convert light energy into chemical energy (1)
○ Plants convert chemical energy into light energy (2)
○ Plants convert light energy into oxygen (3)
○ Plants convert oxygen into light energy (4)

Q: What is the most important source of cellular energy?

○ ATP (1)
○ Chloroplast (2)
○ Oxygen (3)
○ Rhibosomes (4)

Q: What is another name for dark reactions?

○ The Calvin Cycle (1)
○ Thylakoid (2)
○ Stroma Reaction (3)
○ Non-Light Photosynthesis (4)

Inflation quiz questions

Q: What is it called when an economy's demand increases faster than its productive capacity?

○ Demand-Pull Inflation (1)
○ Cost-Push Inflation (2)
○ Material-Dependent Inflation (3)
○ Production-Dependent Inflation (4)

Q: The sharp rise in imported oil prices in the 1970 caused what type of inflation?

○ Cost-Push Inflation (1)
○ Demand-Pull Inflation (2)
○ Material-Dependent Inflation (3)
○ Production-Dependent Inflation (4)

Q: In what circumstance does a borrower benefit most from inflation?

○ If the borrower owed money before the inflation occurred (1)
○ If the borrower owes money after the inflation occurs (2)
○ If the borrower has a high credit score (3)
○ If the interest rates are high on the loan (4)

Q: What result of inflation can be beneficial to lenders?

○ Increased Cost of Living (1)
○ Decreased value of money (2)
○ Emergency US Treasury regulations (3)
○ Inflation is never beneficial to lenders (4)

Q: Which of the following is the formula for calculating inflation?

F = Final value
I = Initial value

○ F - I) / I x 100 (1)
○ F - 1 (2)
○ F - 1 × 100 (3)
○ F x I / 100 (4)

Q: What measure denotes the price of a selection of goods and services for a typical consumer?

○ Consumer Price Index (1)
○ Inflation Coefficient (2)
○ Cost of Living Index (3)
○ Producer Price Index (4)

Autism quiz questions

Q: What medical condition is NOT linked to an increased risk for autism?

○ Leukemia (1)
○ Fragile X Syndrome (2)
○ PKU (3)
○ Congenital Rubella Syndrome (4)

Q: What role does genetics play in developing autism?

○ It is believed that there is a genetic component (1)
○ Genetics do not play a role (2)
○ Autism is believed to be purely genetic (3)

Q: What population makes up the majority of people with Rett's Syndrome?

○ Females (1)
○ Males (2)
○ Adults (3)
○ Teens (4)

Q: What disorder on the autism spectrum is also known as "classic autistic disorder"?

○ Kanner's Syndrome (1)
○ Childhood Disintegrative Disorder (2)
○ PDD-NOS (3)
○ Rett's Syndrome (4)

Q: Which of the following describes how medications are used to treat autism?

○ Medications are used to treat some of the symptoms (1)
○ Medications treat the disease directly (2)
○ Medications are not used with autism patients at all (3)
○ Researchers recently developed a cure for autism (4)

Q: Which of the following is NOT an important method for treating autism?

○ Systematic isolation (1)
○ Behavioural interventions (2)
○ Social skills training (3)
○ Integration into regular classrooms (4)