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Effect of instruction and experience on students' learning strategies

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Abstract
When students are left to choose their own approaches to studying, they frequently engage in ineffective learning strategies, such as rereading textbooks or cramming. Given this natural tendency amongst students, there has been significant interest in how to increase the use of more effective methods of studying. Efforts to-date have typically entailed either explicit instruction (e.g., teaching students which study habits are more/less effective) or direct experience (e.g., having students attempt to utilize an effective technique), yielding somewhat mixed results. The aim of the present study was to examine whether a combination of explicit instruction and direct experience with effective learning strategies positively impacts how students study. After an in-classroom intervention, 316 participants (177 women, M age = 19.03) were asked to indicate how frequently they used various studying strategies and how effective they perceived them to be. Participants demonstrated both a change in knowledge regarding the (low) utility of more ineffective strategies and indicated that they were using those strategies less frequently. However, there was not a global change in their perceptions/use of more effective strategies. Instead, there were increases only for a subset of the more effective strategies. These results support metacognitive theories of desirable difficulties, wherein individuals prefer less effortful strategies and less effortful shifts in behavior, as well as suggest possible directions for furthering effective learning practices amongst students.

Keywords Learning strategies · Effective learning strategies · Instruction · Direct experience

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Introduction

There are substantial individual differences in how well students learn material in their college classes (Cassidy, 2012; Chen et al., 2000). Critically, while some of these differences can likely be captured by inherent differences in the "ability to learn" (e.g., Lyons & Zelazo, 2011; Ahmed et al., 2019), differences in how students approach learning also appear to play a role in their learning and academic performance (Bowen & Wingo, 2012; Bartoszewski & Gurung, 2015; Hassanbeigi et al., 2011). Indeed, because students rarely receive explicit instruction on how to learn, they apply a wide variety of learning strategies including, among others, highlighting, repeatedly re-reading their textbooks, and summarizing their notes (Balch, 2001; Ormrod, 2012; Kornell & Bjork, 2007; Leonard et al., 2021; Hartwig & Dunlosky, 2012).

Given the variety of learning strategies that are naturally employed by students, one major line of research in the literature to-date has focused on the efficacy of different learning strategies (e.g., Donker et al., 2014; Bartoszewski & Gurung, 2015; Hattie & Donoghue, 2018). Some of these studies have examined whether strategies have any utility at all. For instance, many students attempt to study by repeatedly re-reading text. To examine whether rereading of this type increases learning/comprehension, Callender and McDaniel (2009) asked participants to first read, then reread educational texts, and then answer comprehension questions. Immediate rereading of the text did not benefit comprehension, such that participants' performance in the final test was similar to a condition where they had only read the text once. Other studies, meanwhile, have explicitly compared and contrasted different learning strategies with one another. For instance, Butler and Roediger (2007) provided participants with three lectures on consecutive days followed by one of several post-lecture activities: studying a lecture summary, taking a multiple-choice test, taking a short answer test, or doing nothing. Subsequent evaluations of learning showed that learning performance was the best for those students who had taken the short answer test post-lecture, was intermediate for those who had taken a multiple-choice test or had studied a lecture summary and was worst in those participants who completed no post-lecture activity. Given the extensive body of empirical work examining the effectiveness of various learning strategies, researchers have been able to evaluate the overall efficacy of these strategies through meta-analytic techniques. In one of the most comprehensive meta-analyses to date, Dunlosky et al. (2013) found that some strategies, such as summarization, highlighting, and rereading, appear to produce limited benefits for learning performance. Conversely, learning strategies such as practice testing, elaboration, and distributed practice boost learning outcomes in educational settings (Dunlosky et al., 2013).

Interestingly, despite the significant body of scientific work evaluating the effectiveness of certain learning strategies, research suggests that students are often unaware of and rarely choose to engage in learning strategies that have been identified as the most effective learning strategies, like interleaving (Hartwig & Dunlosky, 2012; Karpicke et al., 2009; Kornell & Bjork, 2007; McCabe, 2011; Weinstein et al., 2000; Wissman, & Rawson, 2018). Instead, students disproportionately tend to engage in strategies that are largely ineffective, such as highlighting text (e.g., Hartwig & Dunlosky, 2012), rereading textbooks (e.g., Karpicke et al., 2009), cramming, and using blocked rather than interleaved bouts of studying (e.g., Blasiman et al., 2017; Susser & McCabe, 2013).

The substantial mismatch between the learning strategies that students employ and the learning strategies that are effective at producing learning has led investigators to examine methods to increase the extent to which students employ better learning strategies.

Unfortunately, these attempts have thus far had mixed success (e.g., DeWinstanley & Bjork, 2004; Gurung & Burns, 2019; Koriat & Bjork, 2006). Researchers have most commonly used some form of direct instruction regarding best-practices learning strategies, such as presenting instructional videos (Cathey et al., 2016) or giving explicit verbal instruction (Ariel & Karpicke, 2018). Some studies have observed positive results. Brown-Kramer (2021) asked students to read articles about the effectiveness of various learning strategies (e.g., rereading, practice testing, distributed practice) and write papers summarizing and analyzing the main findings throughout the semester. They found that students' learning strategy preferences shifted from more ineffective strategies toward more effective strategies across the semester. However, several other studies have been unsuccessful in shifting students' beliefs or behaviors via direct instruction (for a review Dembo & Seli, 2004; Hattie et al., 1996). For example, Van Overwalle and Metsenaere (1990) provided participants with a learning strategy course in which students were provided direct instruction on effectiveness in learning strategies. Students' performance on the final test did not improve following the instruction. Researchers interpreted this as the implication of lack of usage of the effective strategies. In total, the existing body of work suggests that, at least in the short term, direct instruction appears to produce some change in students' understanding of learning strategies. Yet, it is critical to note that there is often a mismatch between understanding and behaviors. For example, Foerst et al. (2017) used the Self-Regulated Learning Questionnaire for Action and Knowledge (SRL-QuAK) to examine the discrepancy between students' knowledge and their actions. They found that even if students know about effective learning strategies, their behaviors are unlikely to be aligned with their knowledge.

The second route that researchers have used in attempting to alter students' use of learning strategies is to provide direct experience with more effective strategies (e.g., knowledge updating; see for review Dunlosky & Hertzog, 2000). This involves directly having students employ more effective strategies, such as distributing or interleaving their practice, and allowing them to learn through their own monitoring process. This approach has also yielded mixed findings. For instance, Einstein et al. (2012) had students read two passages in the beginning of the semester. Students read one passage twice whereas they read the other one once before completing an immediate practice test on the material. The students were then asked to rate how well they learned from the two different study strategies. On average, students reported learning roughly the same amount for the two passages. One week later, students took a surprise test on both passages and received feedback on their performance. Their performance was better for the passage they had read once and then took a test on than for the passage they had read twice. Later in the semester, students stated that they used practice testing as a study strategy more often than before.

Although this body of research suggests that experience with more effective strategies might produce a beneficial shift in behavior, one obstacle is that individuals often misinterpret their direct experiences. For example, Pan and Rivers (2023) demonstrated the effectiveness of pretesting compared to simply reading through multiple study-test cycles to address participants' misconceptions. Participants often underestimated the benefits of pretesting and tended to prefer reading, even after making multiple attempts with both methods. They also showed that external support is necessary for participants to recognize the effectiveness of the pretesting strategy, highlighting that task experience alone may not be sufficient to correct misconceptions. Similarly, Logan et al. (2012) had participants study a list of items, some via distributed practice (more effective) and some via massed practice (less effective). The participants learned more in the distributed practice condition compared to the massed practice condition. However, the participants incorrectly believed they had learned more in the distributed condition and thus did not significantly shift their

preference toward a more effective strategy. Interestingly, even if they provided participants with feedback indicating their performance was better in the distributed practice condition, participants' assumptions changed only minimally. This is consistent with the more global finding that students believe less effortful learning strategies are more effective, even if more effortful ones enhance learning and long-term retention (i.e., desirable difficulties; Koriat & Bjork, 2006; McCabe, 2011; Kirk-Johnson et al., 2019).

In sum, it appears that direct instruction and experience-based interventions produce mixed impacts on students' use of learning strategies. In this study, we investigated whether a combination of these two routes - direct instruction and experience with best practices in learning - positively impacts students' perceptions and implementation of effective learning strategies in current and future classes. This combination would take advantage of the fact that individuals are generally more receptive to shifts in behavior when they are shown rather than told, while, at the same time, explicitly addressing misconceptions that direct experience with more effective strategies often produces (e.g., Carpenter et al., 2013; Curioni & Lourenco, 2005; Dombrowski et al., 2010). Thus, our central hypothesis was that a combination of direct instruction and experience with effective learning strategies would produce a positive shift in participants' beliefs about the utility of several learning strategies and an increase in the reported use of those strategies. We further hypothesized that the opposite shift would occur for ineffective learning strategies that research has suggested are not valuable for learning.

Method

Study overview

We assessed the beliefs about and use of various learning strategies in participants drawn from one section of Introductory Psychology (which we refer to as the "Intervention groups" section below) that employed a combination of explicit instruction about, and direct experience with, learning strategies. We contrasted this data against the same measures acquired from participants that were drawn from several business-as-usual sections of Introductory Psychology. Our primary dependent measures were taken in the middle-to-end point of the semester (i.e., after participants in the intervention section had received their instruction about and substantial experience with effective learning strategies). Our primary question was whether those students given explicit instruction about and direct experience with effective learning strategies showed differential beliefs, behaviors, both, or neither at the conclusion of the semester (i.e., a between-groups post-intervention design).

Furthermore, because we had also acquired equivalent baseline measures at the start of the semester for some of the participants (as part of an initial survey for the Psychology Department), we could perform additional analyses directly examining changes in beliefs about and/or use of learning strategies (i.e., a pre-test → post-test design) for a subset of participants.

Participants

Participants were undergraduate students, 18 years or older, at a large public midwestern university who were enrolled in Introduction to Psychology during the Spring 2021 semester. Students signed up to participate through the university's online subject pool system starting

during the fourth week of classes (i.e., after the "Intervention groups" section had provided direct instruction about and had started to provide direct experience with effective learning strategies; see below). Participants could continue to sign up for the study throughout the remainder of the semester. In all, 316 participants participated (177 women, M_{age} = 19.03). Of these participants, 150 (101 women, M_{age} = 18.95) had also taken part in an initial survey offered to all students in all sections of Introductory Psychology at the very start of the semester, in which we had included the same measures assessing beliefs about/use of learning strategies. Therefore, for this subset of participants we have the equivalent of a "baseline" measure (i.e., pre-test measure, prior to instruction/experience). All participants provided consent to participate in accordance with an approved IRB protocol. Participants who took part in the study received course credit for their participation (Table 1).

Procedure

Intervention groups

We were interested in whether a combination of direct instruction and experience with best practices in learning, as instantiated in Introduction to Psychology, leads to better learning practices. We took advantage of naturally differing coverage of various learning principles across sections of Introduction to Psychology. There were five sections of Introduction to Psychology in total.

Intervention section One of the sections of Introduction to Psychology has dedicated coursework on effective learning practices and formal instruction about learning principles (we refer to this as the Intervention groups section). In particular, the intervention section contains a full dedicated course module that focuses explicitly on effective learning strategies. This module covers principles related to the importance of spacing learning rather than cramming, interleaving learning rather than blocking, and active retrieval-based learning. The instruction encourages students to actively engage with material via deep processing rather than shallow processing, and apply their knowledge as opposed to passively receiving information. Additionally, this module underscores the significance of exposing learners to a wide range of contexts and situations throughout their learning process (i.e., contextual variability). There are also some learning strategies mentioned as part of the module, but which are covered to a much lesser extent, such as notetaking, flashcards as examples of active learning, and collaborative group studying, which involves students practicing self-explanation, explaining concepts to each other using real-life examples to promote a deeper understanding of the material. Moreover, the module also covers common strategies that students employ when attempting to learn, but where the available data suggests the strategies have limited effectiveness. These include passively highlighting text, re-reading text, copying notes, summarizing, cramming and keyword mnemonic.

Table 1 Number of participants who participated in pre-test only, post-test only, or both pre-test and post-test

Sections/Parts	Pre-test only (N = 137)	Pre-test & Post-test (N = 150)	Post-test only (N = 166)
Intervention	N = 79	N = 62	N = 56
Business-as-usual	N = 58	N = 88	N = 110

Critically, in addition to providing formal instruction on these best practices, the course also directly implements the practices in the course, more or less forcing the students to utilize best practices. This includes having four weekly quizzes, all of which are cumulative, and which can be retaken repeatedly until a desired grade is achieved (noting that the questions on these quizzes are pulled randomly from a large test bank and thus even when "retaking" quizzes, students are getting new questions each time). These quizzes not only highlight the value of active rather than passive learning (e.g., utilizing test-based learning), but the cumulative nature emphasizes both the value of distributing practice through time as well as interleaving material. Students are not allowed to sit in the same seat throughout the class, but instead must move around the classroom (and are encouraged to study in multiple locations as well), thus highlighting the importance of variability in learning contexts (Raviv et al., 2022). Students are asked to generate their own quiz questions using their personal life experiences as inspiration, thus stressing the value of deeper levels of processing and greater links to memory. Students actively engaged in group discussion activities within their assigned groups during each lecture to brainstorm methodological and contextual questions related to the designated article of the week, demonstrating the implementation of group study. Finally, in addition to the explicit instruction and direct practice, students also received explicit instruction around how the course implemented the best practices (e.g., "…the consistent quizzing that you all complete in this class is a form of active learning and more specifically the testing effect…").

Business-as-usual controls Some of the same material, such as the retrieval practice effect, active learning, and deep processing, were briefly introduced in the other four sections, which were taught by two different instructors as part of the broader learning and memory lecture. However, these concepts were covered considerably less extensively. Similarly, while a few strategies had some degree of implementation in the other sections (e.g., some of the other sections did include weekly non-cumulative quizzes), this was again, done in a considerably less extensive manner. We thus combined the remaining sections and treated them as a business-as-usual control group (note we confirmed that there were not significant differences across these sections in any of the core assessments of interest).

Assessments

Participants completed all assessments online via Qualtrics. Participants were asked to indicate their frequency of use and perceived effectiveness of a set of learning strategies including rereading, cramming, highlighting, note-taking, practice test, looking over notes, copying notes, summarizing, highlighting notes/text, using flashcards, thinking of real-life examples, creating an outline, and group studying. They rated their frequency of use and the perceived effectiveness of twelve possible study strategies on a scale of 1–10. For the former, they responded to the question, "*How frequently have you been using each of the following studying methods this semester?"* For the latter, they responded to the question, *"How would you rate the effectiveness of each of the following studying methods?"* Participants also responded to a set of attention-related questions to indicate how likely they were to prevent distractions from interfering with their study (e.g., I isolate myself from noisy places while studying; I avoid using devices while studying, etc.). Finally, in addition to the use/perceived effectiveness questions, we also sought to determine if participants could recognize effective/ineffective strategies in the context of hypothetical scenarios (for more examples, see https://osf.io/jtxba/?view_only=aeeefedd288046b78ce116f2de61f4d3). In

these scenario questions, participants were asked to choose which of several possible strategies they would be more likely to use if they were a student in that situation.

We also collected a set of individual difference measures including those related to personality, metacognitive abilities, and mindset for intelligence. We measured personality traits with a Big Five Inventory (BFI) (John & Srivastava, 1999). The scale we utilized has 44 items that assess the five different aspects of personality: openness to experience, conscientiousness, extraversion, agreeableness, and neuroticism. To examine participants' metacognitive abilities, we used the Motivated Strategies for Learning Questionnaire (MSLQ) (Pintrich, 1991). The MSLQ consists of two main sections: motivation and learning strategies. The motivation part contains 31 items for evaluating the course goal and value, and the learning strategies part contains 31 items for measuring cognitive and metacognitive strategies and 19 items for managing resources. Finally, we measured participants' mindset for intelligence (i.e., whether they believe that intelligence can/cannot be changed) via a 20-item questionnaire (Dweck, 2006). We also measured academic performance (e.g., GPA, expected grade for the Introduction to Psychology class, SAT).

Results

All data analyses were done through R (R Core Team, 2022). The data files and script folders, where all data analyses are performed, are available on the Open Science Framework (OSF - https://osf.io/jtxba/?view_only=aeeefedd288046b78ce116f2de61f4d3). For the main analyses, we calculated two separate aggregate scores, dividing learning strategies into two groups: effective and ineffective strategies. We used the classifications given by a meta-analysis of Dunlosky et al. (2013) and a comprehensive review of existing literature in determining the categorization of effective and ineffective strategies prior to our study. *Taking tests, flashcards, real-life examples, outline, and group study* were all categorized as effective strategies. The scores of each participant across these were combined to create an aggregate score for effective strategies. *Highlighting, copying notes, copying the textbook, cramming, rereading, and summarizing* were categorized as ineffective strategies. The scores of each participant across these were combined to create an aggregate score of ineffective strategies. We also calculated aggregate scores for *scenarios.* In all cases high scores referred to higher perceived effectiveness and higher frequency of use. The data analysis process had several steps based on our main questions and the data collected in the various parts of the study.

Baseline comparison of groups

Because we had baseline data from the initial survey, we could compare the baseline effectiveness and frequency ratings of participants from the different sections ($N = 134$). The results showed that groups did not significantly differ on any of their pre-test scores: frequency of use of effective ($M_{intervention} = 6.63$, $M_{business-as-usual} = 6.29$), $F(1,134) = 0.36$, $p = .54$, and ineffective strategies ($M_{intervention} = 6.58$, $M_{business-as-usual} = 6.31$), $F(1,134) = 0.24$, $p = .62$. They also did not significantly differ either on the perceived effectiveness of effective ($M_{intervention} = 7.95$, $M_{business-as-usual} = 7.57$), $F(1,134) = 1.65$, $p = .20$ or ineffective strategies ($M_{intervention} = 6.71$, $M_{business-as-usual} = 6.56$),, $F(1,134) = 0.01$, $p = .91$. Thus, there is no evidence to suggest that the groups differed prior to engaging with their Introduction to Psychology materials.

Use and perceived effectiveness of effective and ineffective learning strategies after the intervention

Given the finding above that the groups did not significantly differ at pre-test, we next examined the possible impact across time between groups (intervention vs. business-as-usual). As such, the analysis was restricted to just those participants for whom we had both baseline and post-intervention measures. To examine whether participants enrolled in the section that heavily covered best learning practices (intervention group) changed their beliefs about learning strategies or their use of learning strategies as compared to the sections without heavy coverage of best learning practices (business-as-usual group), we ran a linear regression analysis to compare them on each of the four dependent variables (i.e., the perceived effectiveness of the effective strategies, the perceived effectiveness of the ineffective strategies, frequency of use effective strategies, and frequency of use ineffective strategies). We ran a linear regression where perceived effectiveness and frequency of use at post-test were regressed on group, controlling for baseline.

The regression analyses on effective strategies revealed that the intervention group ($M_{pre-test}$ = 7.95, $M_{post-test}$ = 7.37) and the business-as-usual group ($M_{pre-test}$ = 7.57, $M_{post-test}$ = 7.52) did not differ in their perceived effectiveness score, $F(2,147) = 0.30$, $p = .58$, $\eta^2 = 0.002$ (Fig. 1a). The intervention group ($M_{pre-test} = 6.63$, $M_{post-test} = 5.82$) and the business-as-usual group ($M_{pre-test} = 6.25$, $M_{post-test} = 5.52$) also did not differ in their frequency of use, $F(2,147) = 1.48$, $p = .58$, $\eta^2 = 0.009$ (Fig. 1b). In other words, participants in the intervention group and business-as-usual group rated the effectiveness of effective strategies similarly at post-test after controlling for baseline scores. They also rated learning strategies similarly in terms of their frequency of use.

The regression analysis on ineffective strategies revealed significant results both for frequency of use and perceived effectiveness. Participants in the intervention group ($M_{pre-test}$ = 6.71, $M_{post-test}$ = 4.18) rated ineffective strategies as less effective compared to participants in the business-as-usual group ($M_{pre-test}$ = 6.56, $M_{post-test}$ = 5.79), $F(2,147) = 46.37$, $p < .001$, $\eta^2 = 0.23$ (Fig. 2a). Moreover, participants in the intervention group ($M_{pre-test}$ = 6.58, $M_{post-test}$ = 4.83) also stated that they were less likely to use the ineffective strategies compared to participants in the business-as-usual group ($M_{pre-test} = 6.31$, $M_{post-test} = 5.65$), $F(2,147) = 10.89$, $p = .001$, $\eta^2 = 0.07$ (Fig. 2b).

Converging results - analyses of individuals who only took part in the posttest

We next analyzed the data from participants who participated in the post-test only (and thus in these analyses we could not control for baseline ratings). We ran a linear regression where we regressed their perceived effectiveness and frequency of use ratings for ineffective and effective strategies on the group variable. We compared the intervention group with the business-as-usual group in their ratings. The analysis with the participants who only attended post-test revealed the same pattern of the results as seen above.

Participants' ratings for effective strategies did not differ across the intervention ($M_{post-testonly}$ = 5.61) and the business-as-usual ($M_{post-testonly}$ = 5.26) groups in their perceived effectiveness score, $F(1,164) = 3.18$, $p = .08$, $\eta^2 = 0.01$ (Fig. 3a). The intervention group ($M_{post-testonly}$ = 7.62) and the business-as-usual group ($M_{post-testonly}$ = 7.16) also did not differ in their frequency of use, $F(1,164) = 1.96$, $p = .16$, $\eta^2 = 0.005$ (Fig. 3b).

Participants in the intervention group ($M_{post-testonly}$ = 4.77) gave lower ratings for the ineffective strategies in terms of frequency of use, $F(1,164) = 14.5$, $p < .001$, $\eta^2 = 0.97$, than

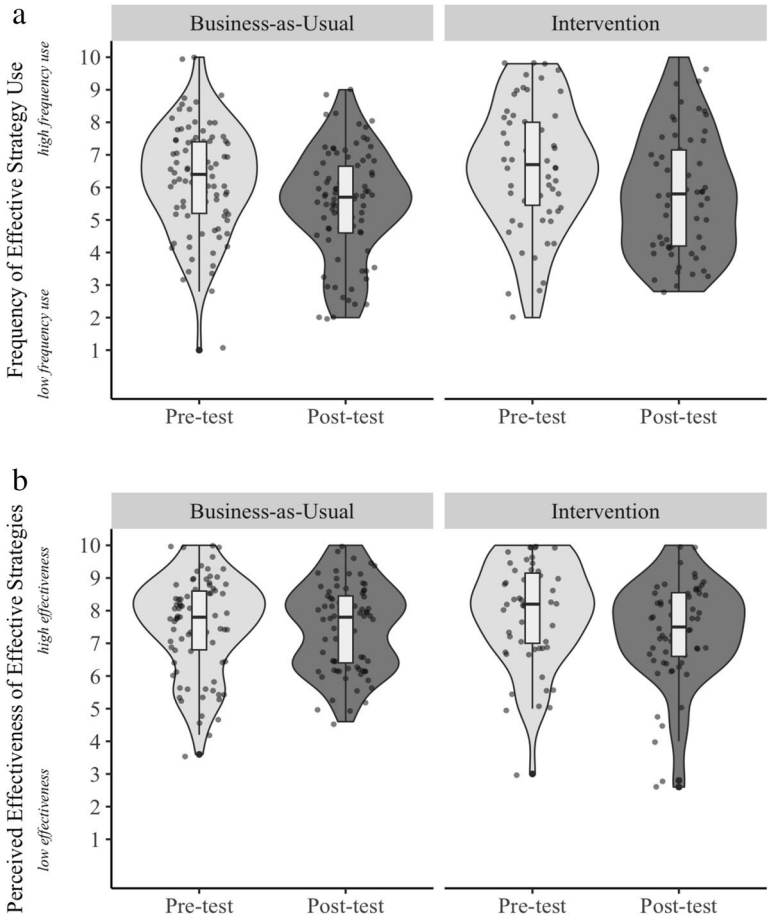

Fig. 1 **a** Pre-test and post-test ratings of perceived effectiveness of effective strategies. **b** Pre-test and post-test ratings of frequency of use of effective strategies

the participants in the business-as-usual group ($M_{post-testonly} = 5.73$) (Fig. 4a). Participants in the intervention group ($M_{post-testonly} = 4.28$) also gave lower ratings for the ineffective strategies in terms of perceived effectiveness than the participants in the business-as-usual group ($M_{post-testonly} = 5.90$), $F(1,164) = 37.22$, $p < .001$, $\eta^2 = 0.18$ (Fig. 4b).

Detailed analyses of each of the twelve learning strategies

As noted above, while our primary goal was to examine changes in beliefs/behaviors related to "more effective" versus "less effective" learning strategies (i.e., as broader categories), we also acknowledged that it was unlikely from the outset that changes in knowledge/behavior would be identical across all the "effective" strategies and/or all the "ineffective" strategies. Therefore, in addition to the main analyses above, we also conducted separate linear regression analyses where ratings in post-test for each strategy (re-reading, looking at notes, copying notes, summarizing, taking-tests, highlighting,

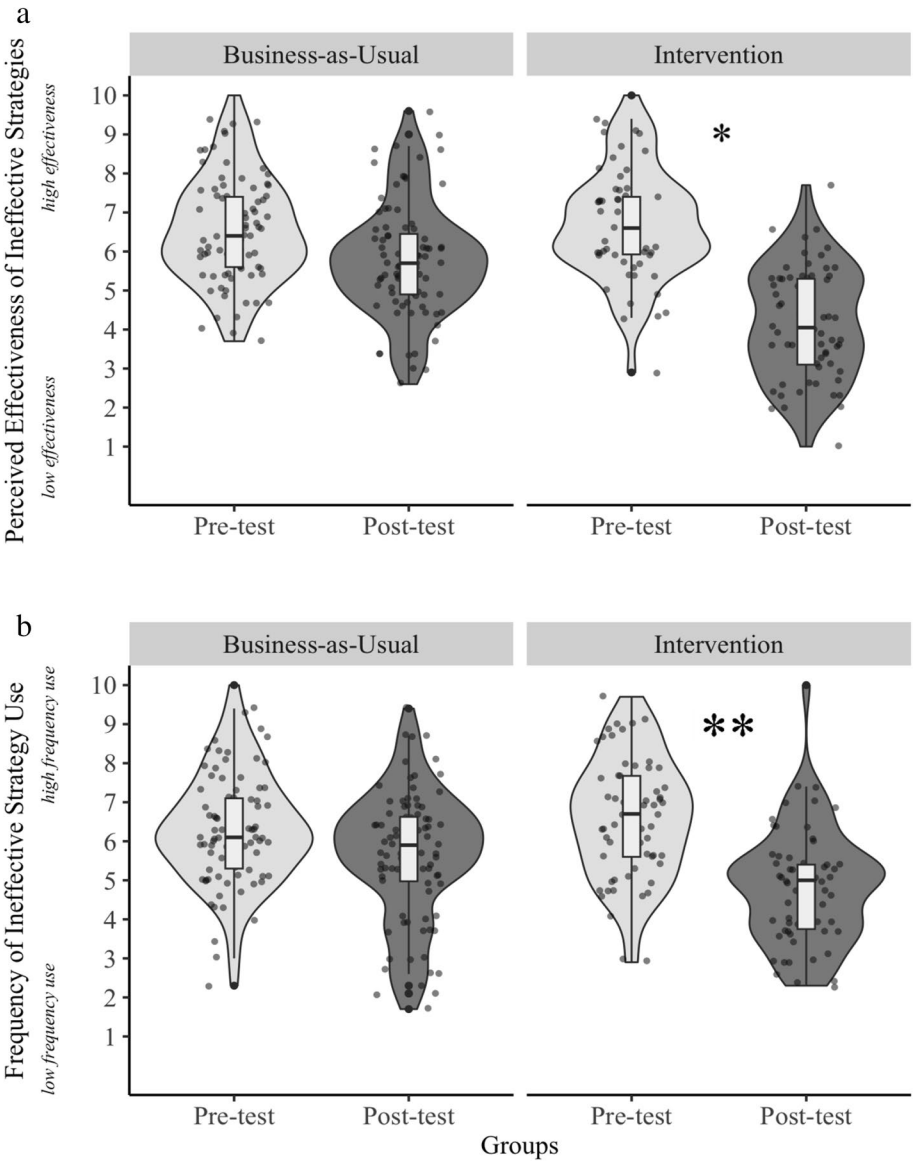

Fig. 2 **a** Pre-test and post-test ratings of perceived effectiveness of ineffective strategies. Note: $*p < .05$, $**p < .001$. **b** Pre-test and post-test ratings of frequency of use of ineffective strategies. Note: $*p < .05$, $**p < .001$

flashcards, real-life examples, creating an outline, cramming, group studying) were regressed on group (intervention vs. business-as-usual) after controlling for baseline ratings. The results revealed that the intervention and business-as-usual groups were significantly different in terms of the perceived effectiveness and frequency of use ratings at post-test for some of the strategies, but not for others (Tables 2 and 3).

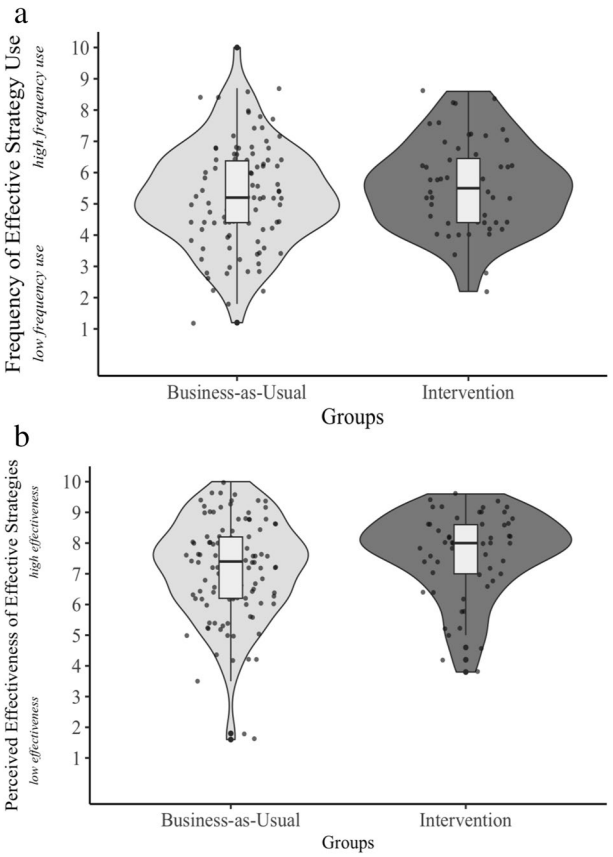

Fig. 3 **a** Ratings of frequency of use of effective strategies of participants who only took part in post-test. **b** Ratings of perceived effectiveness of effective strategies of participants who only took part in post-test. Note: $*p < .05$, $**p < .001$

For the effective strategies, participants' reported perceived effectiveness and frequency of use ratings differed across groups for test-taking $F(2,147) = 4.02$, $p = .01$ with those in the intervention group indicating higher perceived effectiveness and more frequent use of test-taking as a learning strategy. The equivalent analyses for using real-life examples, creating an outline, and for group study failed to reach significance. Finally, the results revealed a significant difference across the intervention and business-as-usual groups for flashcards, but in the opposite direction, $F(2,147) = 13.30$, $p < .001$ (i.e., students in the business-as-usual group indicated higher perceived effectiveness and frequency of use than those in the intervention condition). This latter result was likely attributable to the fact that students in the intervention section were informed that flashcards are effective for rote memorization, but perhaps less so for deeper forms of comprehension or learning. We return to this point in the discussion.

For the ineffective strategies, participants' perceived effectiveness and frequency of use ratings for re-reading $F(2,147) = 16.63$, $p < .001$, looking at notes $F(2,147) = 7.05$, $p = .001$, and highlighting $F(2,147) = 27.71$, $p < .001$ were significantly different across groups in the expected direction (i.e., intervention group indicating lower perceived effectiveness and less frequent use). However, these analyses were not significantly different for cramming, summarizing, and copying notes.

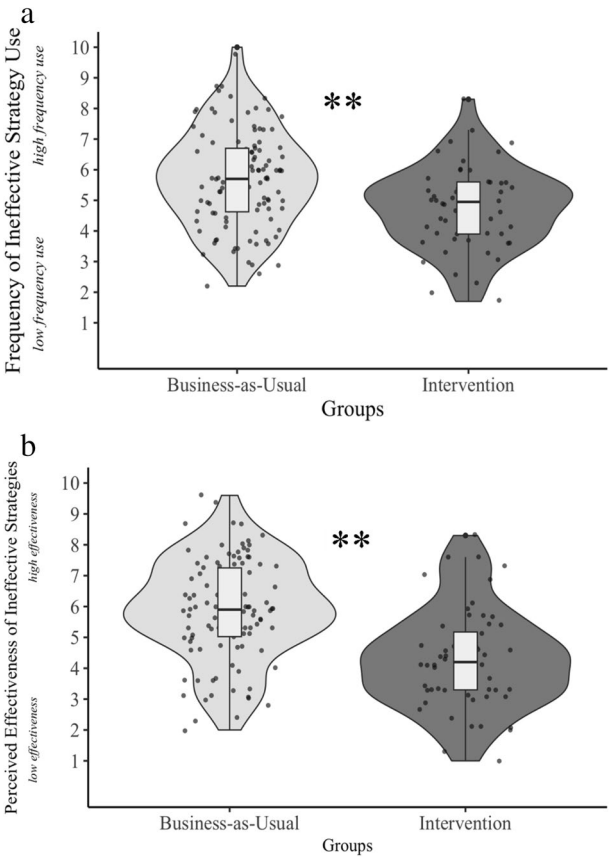

Fig. 4 Ratings of frequency of use of ineffective strategies of participants who only took part in post-test. Note: *$p < .05$, **$p < .001$. **b** Ratings of perceived effectiveness of ineffective strategies of participants who only took part in post-test. Note: *$p < .05$, **$p < .001$

Table 2 Ratings of perceived effectiveness of learning strategies

Learning strategies	Intervention		Business-as-usual		p value
	Pre-test	Post-test	Pre-test	Post-test	
Reading textbook	6.67	3.87	6.34	6.45	$p < .001$**
Taking tests	9.10	9.71	9.11	9.12	$p = .02$*
Using life examples	8.37	8.18	7.50	8.17	$p = .91$
Looking at notes	8.29	5.85	8.55	7.31	$p < .001$**
Highlighting notes	6.85	2.34	6.76	5.32	$p < .001$**
Creating outlines	7.18	6.05	7.18	6.14	$p = .85$
Copying notes	6.65	5.24	6.41	5.74	$p = .29$
Highlighting textbook	6.34	1.76	5.81	4.49	$p < .001$**
Cramming	4.11	3.42	3.97	3.93	$p = .22$
Summarizing notes	8.00	6.73	8.10	7.43	$p = .07$
Using flashcards	7.74	6.19	7.32	7.74	$p < .001$**
Group study	7.39	6.71	6.74	6.44	$p = .46$

The ratings are on a scale of ten

Table 3 Ratings of frequency of learning strategy use

Learning strategies	Intervention		Business-as-usual		p value
	Pre-test	Post-test	Pre-test	Post-test	
Reading textbook	6.60	3.39	5.98	5.69	$p < .001$**
Taking tests	8.11	9.23	8.14	7.19	$p < .001$**
Using life examples	7.31	6.95	6.82	6.40	$p = .19$
Looking at notes	8.50	7.90	8.55	7.95	$p = .90$
Highlighting notes	6.74	2.97	6.77	5.33	$p < .001$**
Creating outlines	6.39	4.90	5.34	4.28	$p = .23$
Copying notes	5.77	5.85	5.26	5.03	$p = .11$
Highlighting textbook	5.26	1.81	4.57	2.93	$p = .005$*
Cramming	6.02	5.94	5.59	6.72	$p = .06$
Summarizing notes	7.18	5.94	7.42	5.93	$p = .98$
Using flashcards	5.92	4.16	5.16	5.86	$p = .002$*
Group study	5.40	3.87	5.31	3.84	$p = .92$

The ratings are on a scale of ten

Scenario analyses

Finally, at post-test, participants ($N = 316$) were asked to rate how they would act in various scenarios (i.e., which of several possible learning strategies they would use in the given scenario). As such, for this data, we examined all individuals who took part in post-test (regardless of whether they took part in pre-test). We calculated one aggregate score per participant. We conducted a between-group analysis to examine the effect of the group (intervention vs. business-as-usual) on the participants' aggregate score for scenarios. A linear regression where the scenarios' scores regressed on the groups (intervention vs. business-as-usual) showed that the intervention group ($M = 8.23$) chose effective strategies over ineffective ones more often than the business-as-usual-group ($M = 6.51$), $F(1,314) = 190.1$, $p < .001$, $\eta^2 = 0.38$ (Fig. 5).

Perceived effectiveness & frequency of use

We conducted a Pearson correlation analysis to investigate the relationship between the frequency of use and the perceived effectiveness of various learning strategies. In short, we would expect that if participants perceived a strategy to be effective, they would be more likely to report using that strategy. The analysis revealed a significant correlation between students' perceived effectiveness and the frequency of use of learning strategies in both the pre-test ($r(148) = 0.47$, $p < .001$) and post-test ($r(148) = 0.30$, $p < .001$). This trend persisted in individual analyses examining the correlation between perceived effectiveness and the frequency of use of each learning strategy (for a detailed breakdown, refer to Appendix Table 4).

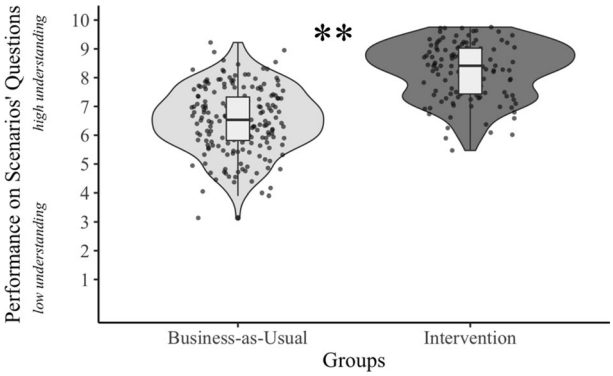

Fig. 5 Scenarios ratings. Note: *$p < .05$, **$p < .001$

Discussion

We examined whether a combination of direct instruction about effective/ineffective learning strategies and direct experience with effective learning strategies could increase participants' knowledge of and reliance on effective learning strategies and/or decrease participants' reliance on ineffective learning strategies. Our results revealed that, relative to the business-as-usual instruction about learning that occurred in other sections of Introduction to Psychology, the intervention increased students' understanding of and beliefs about the effectiveness of various learning strategies reasonably broadly. However, the intervention only broadly shifted their behaviors for ineffective strategies (i.e., there was a significant reduction in the use of ineffective learning strategies), not for effective strategies (i.e., there was not a significant increase in the use of effective learning strategies). While the pattern observed for the ineffective learning strategies is certainly a positive outcome, the pattern seen for the effective learning strategies (i.e., shifts in knowledge, but not in behaviors) is less so. This latter pattern is consistent with many previous studies which have shown that students' knowledge and actions often conflict (Dembo & Seli, 2004; Foerst et al., 2017) and that shifting learning behaviors is a difficult endeavor (Ariel & Karpicke, 2018; Brown-Kramer, 2021, 2022; DeWinstanley & Bjork, 2004; Gurung & Burns, 2019; Koriat & Bjork, 2006).

One explanation as to why there was not a change in behaviors surrounding effective learning strategies, despite an increase in knowledge about those strategies, comes from metacognitive theories of desirable difficulties (Bjork, 1994). Research examining how students monitor their learning has shown that students typically prefer less effortful learning strategies (Koriat & Bjork, 2006) rather than utilizing more effortful learning strategies that would produce long-lasting learning improvement (i.e., they'd prefer to not do the more "difficult" type of learning even if it is "desirable" for learning). It is thus possible that participants felt that shifting their behaviors to align with more effective strategies was simply more effort than they were willing to put in (and more effort than reducing their use of ineffective strategies). Indeed, there are many cases in the behavioral sciences where individuals are taught best practices in behavior but then do not go on to utilize those practices going forward (e.g., with respect to healthy eating, regular exercise) (e.g., Thomson & Ravia, 2011 see for review Hillsdon, 2005; Norman, 2007; Williams, & French, 2011). For example, people may know that they need to start working out, but they may not follow through due to the effort and discomfort associated with it. This is

particularly common in cases where the best practice behaviors feel effortful or difficult, which can be true of many of the most effective studying practices.

A second possible reason why students did not increase their use of effective learning strategies is that they did not fully understand how these strategies were impacting their performance through their experience. McDaniel et al. (2021) proposed that students should not only understand the effectiveness of learning strategies but should also be committed implementing strategies into their learning, which involves recognizing the value of these strategies in improving their academic performance. However, even if effective learning strategies were integrated into the students' regular coursework, there was no way to provide the students with a "counterfactual" example. That is, students did not know how their learning would have progressed in the absence of the intervention. Second, the impact of the learning strategies was (necessarily) significantly temporally delayed (i.e., the evidence of better learning came well after the effort was put in). It is therefore possible that the students may not have understood how the effective learning strategies impacted their progress. Students may have understood that such strategies are globally "good," but may not have seen enough evidence with respect to themselves to motivate a switch in behavior.

A third possible explanation for why we failed to see an overall increase in the use of effective strategies might be the content of the various sections. There were clear gradations with respect to how the intervention section covered what we considered here to be "effective strategies." Therefore, while there may be explanations for change in global behaviors, we recognize the need to address the specific factors that influence the adoption of individual strategies. For instance, the intervention section heavily covered the value of active learning (e.g., practice testing). Consistent with this, we saw significant increases in both knowledge and behavior regarding active learning strategies (e.g., testing). This might suggest that individuals need more exposure to and practice with these effective strategies before they can effectively incorporate them into their routines. Conversely, one of the business-as-usual sections noted flashcards as an effective strategy, whereas the intervention section provided a much more nuanced view of flashcards (i.e., suggesting they could be useful for pure rote memorization, but might not be useful for the more conceptual and integrative types of learning emphasized and required in that section of the course). Consistent with this practice, we observed a "reversed" outcome with respect to flashcards; the intervention group indicated a reduced use of flashcards relative to the business-as-usual condition. While this reflects one downside of a "natural experiment," in that we could not perfectly control the content that was being covered across the sections that were examined, it also provides a degree of optimism regarding the utility of the intervention. That is, the strategies that were emphasized did seem to shift at least some behaviors accordingly.

Here we note again that our grouping of strategies into effective and ineffective categories (e.g., based upon external meta-analyses) was meant to create metrics that were at least semi-independent of the specifics of the intervention. However, the patterns observed when the data is broken down by specific strategies (i.e., a very strong alignment with the degree of emphasis and experience in the intervention section) suggests that this may be the best level of analyses for future work.

Additionally, the fact that some students changed their behavior while others did not, highlights the importance of examining individual differences. These differences can provide insight into why students respond differently to the intervention and inform how/why students approach learning. It is worth noting that although we included measurements of individual differences (e.g., metacognitive abilities, mindset) in our study,

in exploratory analyses we did not observe a consistent pattern in how these individual differences impacted the effectiveness of the intervention in our primary exploratory analyses (as these were purely exploratory in nature, they are available on the OSF site for the project). This may be due to the complexity of the relationships between these factors and learning strategies or may indicate that other individual differences not captured in our study may play a more significant role. Further research is needed to better understand the interplay between these individual differences and behavior change in learning, and to identify additional factors that may moderate the effectiveness of interventions. By taking these individual differences into account, we can better understand why changing behaviors may be challenging for some students through interventions and develop strategies to address the unique needs of each student, leading to a greater likelihood of successful change in learning strategies.

An important next step will be examining the long-term effects of the intervention. Many studies to date have focused on immediate changes in people's beliefs, behaviors, and performance after an intervention (Ariel & Karpicke, 2018; Brown-Kramer, 2021; Winstanley & Bjork, 2004; Gurung & Burns, 2019; Koriat & Bjork, 2006). However, it is not clear whether changes in behaviors will persist in the long term. The intervention's successful outcome, including the shift in ineffective strategies and some effective ones such as taking a practice test, highlights the importance of conducting a long-term follow-up study to assess the sustainability of the behavioral changes and gain a better understanding of the intervention's effectiveness. Additionally, investigating how students are utilizing the extra time gained from eliminating ineffective strategies could provide insights into their adaptive learning practices over an extended period. Students may be regulating their study time more efficiently following the intervention by simply eliminating ineffective strategies and incorporating a little self-testing.

Another possible next step would be to conduct a follow-up survey or interview with the students to gain insight into why they did not continue to utilize effective learning strategies. This can help to identify any barriers or challenges they faced. For example, the students may have found the strategies too difficult to incorporate into their routine and may need additional support or guidance in order to effectively transfer these strategies to their self-regulated learning. Alternatively, they might view effective learning strategies as time-consuming, so they may not feel they have enough time to implement them in their study routine.

Overall, the implications of this research are significant for promoting self-regulated learning and improving students' learning outcomes. Consistent with previous research, the present study suggests that students tend to rely on less effortful, familiar learning behaviors even when provided with instructions and experience using more effective strategies (Dunlosky et al., 2013). The current study emphasizes the importance of bridging the gap between memory and learning research and self-regulated learning strategies. Critically, this finding highlights the need for a more holistic approach to evaluate and support students' understanding of learning and memory, as well as their self-regulated learning behaviors. This approach should include an examination of how the education system contributes to this misunderstanding and tendency to use ineffective strategies (see for review Soderstrom & Bjork, 2015); identification of when/where students acquire inefficient self-regulated learning behaviors and how individual differences contribute to different learning strategies and outcomes. This knowledge can then be used to develop effective educational interventions. By integrating our understanding of metacognition and effective learning strategies, researchers and educators can equip students with the toolkit to succeed as learners in their academic and professional pursuits.

Appendix

Table 4 Pearson correlations: Perceived effectiveness and frequency of use for learning strategies

Learning strategies	Perceived effectiveness & frequency of use - Part1	Perceived effectiveness & frequency of use - Part2
Rereading textbook	0.37	0.79**
Looking at notes	0.53**	0.44*
Copying notes	0.66**	0.65**
Summarizing notes	0.42*	0.33
Practice test	0.52**	0.69**
Highlighting	0.72**	0.62**
Flashcards	0.51*	0.72**
Real life examples	0.40	0.73**
Creating outline	0.58**	0.64**
Cramming	0.85**	0.60**
Group study	0.57**	0.56**

*indicates $p < .05$. ** indicates $p < .01$

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Data Availability The data is available on the OSF site for this project, and the link to the OSF page can be found under the method section.

Declarations

The authors have no relevant financial or non-financial interests to disclose.

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