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INTERVENTION STUDY

Growing Out of the Experience: How Subjective Experiences of Effort and Learning Influence the Use of Interleaved Practice

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Abstract

In higher education, many students make poor learning strategy decisions. This, in part, results from the counterintuitive nature of effective learning strategies: they enhance long-term learning but also cost high initial effort and appear to not improve learning (immediately). This mixed-method study investigated how students make learning strategy decisions in category learning, and whether students can be supported to make effective strategy decisions through a metacognitive prompt, designed to support accurate monitoring of effort and learning. Participants ($N = 150$) studied painting styles through blocked and interleaved practice, rated their perceived effort and perceived learning across time, and chose between either blocked or interleaved practice. Half of the participants ($N = 74$) were provided with a metacognitive prompt that showed them how their subjective experiences per strategy changed across time and required them to relate these experiences to the efficacy of learning strategies. Results indicated that subjective experiences with interleaved practice improved across time: students' perceived learning increased as their perceived effort decreased. Mediation analysis revealed that the increased feeling of learning increased the likelihood to select interleaved practice. The percentage of students who chose interleaved practice increased from 13 to 40%. Students' learning strategy decisions, however, did not benefit from the metacognitive prompt. Qualitative results revealed that students initially had inaccurate beliefs about the efficacy of learning strategies, but on-task experiences overrode the influence of prior beliefs in learning strategy decisions. This study suggests that repeated monitoring of effort and learning have the potential to improve the use of interleaved practice.

Keywords Self-regulated learning · Mental effort · Perceived learning · Desirable difficulties · Effective learning strategies · Interleaved practice

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In higher education, students have substantial freedom to monitor and control (i.e., self-regulate) their learning (Bjork et al., 2013). One way that students can exert control over their learning is deciding *how* to study (e.g., re-reading a textbook or answering practice questions). Such decisions are critical because the use of learning strategies is an important predictor of learning outcomes (Dunlosky et al., 2013). Many students, however, make poor learning strategy decisions (Blasiman et al., 2017), such that they avoid effortful but effective strategies — the so-called desirable difficulties (Bjork, 1994) — in favor of less effortful but less effective strategies (e.g., highlighting text). One plausible explanation for these poor strategy decisions is that students struggle to assess the efficacy of learning strategies due to their inaccurate monitoring of effort and learning (Baars et al., 2020; de Bruin et al., 2020; Kirk-Johnson et al., 2019). For example, when monitoring their learning, students overlook the benefits of effective strategies, since gains in one's learning often appear after a delay (Bjork & Bjork, 2011; Roediger & Karpicke, 2006). In the absence of immediate perceived learning gains, students associate the high mental demands related to effective strategies with low learning (Baars et al., 2020). This subjective experience of effort, in turn, might misinform students regarding the efficacy of learning strategies (Biwer et al., 2020) and contribute to their poor strategy decisions (Kirk-Johnson et al., 2019).

A promising way to counter inaccurate monitoring of effort and learning is providing students with metacognitive prompts (de Bruin & van Merriënboer, 2017). Metacognitive prompts refer to facilitative tools (e.g., questions, hints, and visualizations) that help students to monitor their learning and reflect upon their task experiences (Bannert, 2006). Previous studies have shown that metacognitive prompts can increase students' access to diagnostic indicators (or "cues") about their current state of knowledge (van de Pol et al., 2020). Using diagnostic cues, students can monitor their learning more accurately and therefore improve their control decisions, such as re-study choices (Wiley et al., 2016).

Presumably, metacognitive prompts can also help students overcome their biases about effective learning strategies, by helping students to make more valid inferences from their on-task experiences. In our view, this can be achieved in two steps. First, through a metacognitive prompt, students can be induced to monitor their on-task experiences across time and zoom out of their immediate and often misleading experiences with effective strategies. Students will thereby be able to recognize that effective strategies become less effortful across time, as perceived effort tends to decrease with increased task familiarity (Andersen et al., 2018). Furthermore, they will be able to recognize that effective strategies benefit their learning, since delayed learning gains will become more apparent to students (Yan et al., 2016). Then, the second step involves that students should be encouraged to explicitly reflect on how their on-task experiences change across time, given that they may struggle to recognize such improvements while simultaneously performing a learning task (Tullis et al., 2013). In this study, we tested the effectiveness of such a metacognitive prompt to improve learning strategy decisions in category learning.

Strategy Decisions in Category Learning: Interleaved Versus Blocked Practice

In this study, we focused on examining students' perceived effort and perceived learning in a categorical learning task, which is a ubiquitous task for many students, be it for children who learn arithmetic rules or medical students who learn different types of diseases. Typically, students learn categories by studying exemplars (Carvalho & Goldstone, 2017), e.g., a medical student can learn how to diagnose a type of lung infection by inspecting multiple X-rays that belong to a diagnostic category. In category learning, blocked and interleaved practice are two main strategies that students can use (Kornell & Bjork, 2008). Both strategies relate to the order of learning materials: Blocked practice entails a fixed study order, in which students inspect all the exemplars of the same category before inspecting exemplars from a different category. This helps students to detect commonalities within categories. Interleaved practice entails a mixed study order, in which students inspect mixed exemplars from different categories. This helps students to detect differences between categories (Carvalho & Goldstone, 2017). In various domains, it has been shown that interleaved practice results in better category learning than blocked practice, such as science (Eglington & Kang, 2017), statistics (Sana et al., 2017), and arts (Kornell & Bjork, 2008).

Several studies showed that over 60% of the students judged blocked practice to be a more effective strategy than interleaved practice, even though interleaved practice enhanced their category learning more than blocked practice (Birnbaum et al., 2013; Kornell et al., 2010; Zulkiply et al., 2012). This suggests that many students are unable to infer the efficacy of interleaved practice from their task experiences (Kornell & Bjork, 2008). Arguably, this metacognitive illusion results from the inaccurate monitoring of effort and learning during strategy execution (de Bruin et al., 2020). Supporting this argument, Kirk-Johnson et al. (2019) found that students perceived interleaved practice as more effortful than blocked practice, and this additional effort demand was negatively associated with their perceptions about the efficacy of interleaved practice and their strategy choices. In relation to monitoring of learning, Yan et al., (2016 Exp. 1 A/B) showed that students assigned higher learning judgments to blocked learning materials than for interleaved learning materials, especially at the onset of the study. Their results revealed that students could recognize the learning benefits of interleaved practice after time, but even then, only 13% of the students endorsed interleaved practice as a more effective strategy. These studies emphasize that students need more support in monitoring their subjective experiences during strategy execution, as well as using these experiences to update their knowledge about the efficacy of learning strategies.

Improving Learning Strategy Decisions

As mentioned, students seem to make poor strategy decisions due to the intricate relationships between their perceived effort, perceived learning, and perceived efficacy of learning strategies: Effective strategies typically require high initial invested effort and students experience no immediate learning gains. These experiences, in turn, mislead students' perceptions of the efficacy of these strategies. However, previous strategy interventions have only targeted this effort, learning, and efficacy triangle in isolation; they mainly focused on showing or informing students that effective learning strategies benefit their learning and overlook the role of perceived effort. For example, several studies used performance feedback to counter inaccurate perceived learning (Carpenter et al., 2017; Hui et al., 2021). Typically, these studies presented students their actual test scores after students implemented two contrasting learning strategies. For instance, Hui et al. (2021) had students inspect their test-scores after studying human anatomical structures through theoretically (in)effective strategies (re-study and retrieval practice, respectively). Their results showed that only a subset of students — i.e., those who remembered more of the retrieval practice items than of the re-study items — increased their use of retrieval practice. However, researchers found that other students showed no improvements. This study shows that performance feedback alone may be insufficient to improve learning strategy decisions, especially when students perform equally well with ineffective learning strategies.

In addition to performance feedback, other studies have used minimal strategy instructions to improve learning strategy decisions (e.g., Ariel & Karpicke, 2018). Often, these instructions informed students about the efficacy of contrasting strategies, without focusing on perceived effort and perceived learning. For instance, Ariel & Karpicke (2018) informed students about the efficacy of retrieval practice and how to use this strategy to maximize their learning (i.e., recall each item correctly at least three times). Their results revealed that informed students engaged in more retrieval attempts than uninformed students did in initial and transfer sessions. Yet, one shortcoming of this study was that informed students were inconsistent in their use of retrieval practice: These students were asked to use retrieval practice until they recalled each item correctly at least three times. However, half of the items were not studied according to this criterion, and students reverted to restudy or dropped the material from the study list. Researchers argued that students may have failed to adhere to this criterion because it was difficult for them to keep track of their responses. Potentially, an intervention that combines the strategy instruction with an experienced-based metacognitive prompt can overcome this shortcoming. For example, this prompt could help students to track their responses and ease the mental burden on students.

Improving the use of interleaved practice, however, might be more challenging than retrieval practice. For example, Yan et al. (2016) tested the effectiveness of performance feedback and minimal strategy instructions to alter students' perceptions about interleaved practice when studying painting styles. Their results revealed that after inspecting their test-scores, only 33% of the students thought interleaved practice was a better strategy than blocked practice, even though 60% of them had performed better with interleaved practice. Subsequently, the researchers tested the effectiveness of minimal strategy instructions. Across multiple experiments, the researchers informed students about the characteristics of blocked and interleaved practice to different extents: Which strategy is more effective, why interleaved practice improves learning, why blocked practice might feel as more effective, and their combination. Here, they found that students struggled to overcome their biases against interleaved practice even after they received the most detailed instructions. This set of findings led to the conclusion that students prefer blocked practice due to the difficulty to discount strong on-task experiences.

Taken together, previous strategy interventions improved learning strategy decisions only partially. Often, these interventions focused on only one aspect of the triangle between students' perceived effort, perceived learning, and perceived effectiveness of learning strategies and overlooked the links between different elements. Furthermore, the role of perceived effort in learning strategy decisions was largely neglected. In our account, an attempt to improve learning strategy decisions should target the whole triangle rather than in isolated parts. Because learners' experiences are initially misleading, this attempt should also allow students to monitor their subjective experiences on multiple occasions across time, through which students can overcome their biases about effective strategies.

Therefore, in this study, we test the effectiveness of a novel approach to improve students' learning strategy decision in category learning. To foreshadow, our approach entailed that students studied various painting styles through blocked and interleaved practice and monitored their subjective experiences of effort and learning across time. We provided half of the students with a visual metacognitive prompt. This prompt provided a visual depiction to students of their subjective experiences (i.e., their ratings of effort and judgments of learning), such that students could examine how their experiences vary between learning strategies and change across time. Furthermore, it invited students to reflect upon their experiences and reason why and how their experiences change (or did not change) in relation to their perceived efficacy of learning strategies.

The Present Study

The purpose of this mixed method study was threefold. First, we examined how students utilized their subjective experiences of effort and learning to make learning strategy decisions in category learning. To this end, we examined how students' subjective experiences varied between learning strategies and changed across time. Previous studies indicated that students experienced interleaved practice as more effortful and less effective than blocked practice, and students avoided interleaved practice because the additional effort demand of this strategy misled their perceptions of learning and thus misled their strategy decisions (Kirk-Johnson et al., 2019). However, what remains unclear is how these experiences change across time due to student-strategy interaction. With this study, we aimed to bring clarity to the dynamic nature of students' on-task experiences and their influence on learning strategy decisions.

Second, the present study tested the effectiveness of a novel metacognitive prompt (henceforth, the visual feedback prompt; the VFP) to improve students' learning strategy decisions. The VFP provided students a visual depiction of their on-task experiences across time: Students could inspect how their subjective experiences of effort and learning change across time when applying blocked and interleaved practice. Furthermore, it created students an additional reflection opportunity, in which students could explicitly reflect on why their on-task experiences change in relation to the efficacy of learning strategies. We argued that this prompt would improve students' learning strategy decisions because students would be able to escape from their misleading on-task experiences that arise at the onset of their study and recognize improvements in effort and learning associated with effective strategies. That is, students would notice that interleaved practice becomes less effortful across time and that it benefits their learning. All in all, students would recognize that the differences in subjective experiences between interleaved and blocked practice become smaller (or disappear, or become reversed), which would increase the likelihood that they would choose interleaved practice.

Finally, the present study aimed to gain more insight into the heterogeneity among students as to (1) why they apply blocked and interleaved practice and (2) how they monitor and regulate their invested effort in learning when using blocked and interleaved practice. Understanding this heterogeneity is important because previous studies (e.g., Hui et al., 2021) showed that not all students benefit from strategy interventions, potentially because students might have different difficulties to adopt effective strategies. To gain these in-depth insights, we complemented our paradigm with a qualitative approach, given that previous studies were predominantly limited to survey studies. Although informative, survey studies are limited because students' responses are restricted to factors predetermined by researchers. Through open questions during the experiment, we had participants elaborate on their strategy decisions after each strategy choice. Furthermore, prompt questions in the VFP captured how students monitored and regulated their subjective learning experiences across time.

We formulated the following research questions:

RQ (1) How do perceived effort and perceived learning vary as a function of blocked and interleaved practice across time?
RQ (2) What are the associations between perceived effort, perceived learning, and the learning strategy decisions?
RQ (3) How does the VFP influence learning strategy decisions?
RQ (4) What other factors affect students' learning strategy decisions?
RQ (5) How do students differ in their monitoring and regulation of effort while using blocked and interleaved practice?

For the first research question, we hypothesized that students would judge interleaved practice as more effortful than blocked practice. Furthermore, we expected that students would judge learning as higher for the painting styles studied with blocked practice than those studied with interleaved practice. As for temporal changes in perceived effort and perceived learning, empirical evidence is limited and it precludes specific predictions. Possibly, perceived effort decreases over time due to increased task familiarity (Andersen et al., 2018), and this decrease will be larger for interleaved practice because this strategy is highly underused by students (Tauber et al., 2013). Given that students might use effort as a cue for their perceived learning, perceived learning would point in the opposite direction of perceived effort, a connection known as the *memorizing effort heuristic* (Baars et al., 2020). For the second research question, we hypothesized that perceived effort would serve as a cue for perceived learning, and perceived learning would mediate the effect of perceived effort on strategy decisions. For the third research question, we hypothesized that VFP would promote the use of interleaved practice if perceived effort and perceived learning change in the expected direction. The fourth and fifth research questions were analyzed qualitatively. Thus, no a priori hypotheses were formulated.

Method

Open Science Practices

We preregistered the study's hypotheses, planned methods, and planned analyses to enhance transparency and reproducibility. The preregistration can be found at the Open Science Framework at (https://osf.io/u6es8/).

Design and Participants

In a 2×2 mixed factorial design, we manipulated learning strategies (blocked practice and interleaved practice) as within-subjects factor, and the presentation of VFP as between-subjects factor. When estimating the sample size, our starting point was to detect the interleaving effect (Kornell & Bjork, 2008), since we built our experiment on the precondition that interleaved practice results in greater category learning than blocked practice. According to a recent meta-analysis (Brunmair & Richter, 2019), the interleaving effect for studying visual categories is medium in effect size (Hedge's $g = 0.67$). Thus, a priori power analysis (repeated measures ANOVA, within-between interaction) was conducted with the effect size set at medium (Cohen's $f = 0.25$), with intercorrelation between repeated measures = 0.3, nonsphericity correction = 1, and 95% power. Based on this calculation in G*Power 3.1 (Faul et al., 2007), at least 76 participants were needed.

Nevertheless, to reach enough power to examine structural relations between perceived effort, perceived learning, and strategy decisions, we collected data from 150 participants (female = 77; male = 73), who were recruited via Prolific online participant recruitment service (https://www.prolific.co/). All participants were undergraduate students ($M_{age} = 22.6$, $SD_{age} = 5.28$, range$_{age}$: 18–50) and English was the predominant first language (85%). Of the participants, 92 were from the UK, 25 were from the USA, and the remaining 33 were from seven different countries. All participants received seven euros in exchange for their participation. The Ethics Review Committee of (institute removed for review) approved the study (reference number: FHML-REC/2020/045).

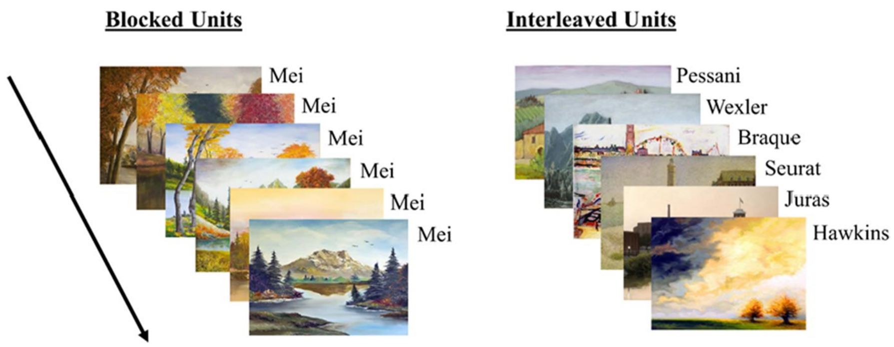


Fig. 1 Strategy units

Materials

Learning Materials

Learning materials were series of paintings of 18 artists, divided into two learning sets. The first set consisted of six paintings by each of 12 different artists, which were used in Kornell & Bjork (2008); this set was used in study phase I. The second set consisted of six paintings by each of six different artists (Claude Lorrain, David Friedrich, Frederic Church, John Constable, Joseph Turner, and Paul Cezanne), which were obtained from the Painting-91 database (Khan et al., 2014); this set was used in study phase II. To induce learning strategies, all paintings were grouped into what we call *strategy-paintings units* (Figs. 1; henceforth, units). In blocked units, there were six paintings by the same artist, whereas in interleaved units, there was one painting by six different artists. All paintings were resized to 425 × 312 pixels.

Perceived Effort

Perceived effort was measured by the single item "how much mental effort did this strategy cost you?" on a 9-point (1: very, very low to 9: very, very high) rating scale (Paas, 1992). In this study, we were interested in the effort induced by learning strategies. Therefore, we adapted the original item, which measures the effort that students invest in learning tasks.

Perceived Learning

Perceived learning was measured using a 9-point subjective rating scale, which asked participants "How likely do you think you are to recognize the paintings of this artist/ these artists in a later test?" (1: very, very unlikely to 9: very, very likely).

Learning Strategy Decision

In a binary choice question, participants selected between blocked and interleaved practice on three occasions: before study phase I, after study phase I, and after the VFP/control condition (see Fig. 3). The first question measured participants' habitual strategy use in category learning (i.e., Which strategy do you typically use during your self-study time?). The second question asked students' strategy preference for a hypothetical study session (i.e., Which strategy would you like to use if you were to study a similar learning task?), while the third question asked their strategy preference to study novel materials (i.e., You will now study six paintings of each of six new artists. Which strategy would you like to use to study these paintings?). The strategy choice questions were always followed by an open question (i.e., Could you please explain why you would use this strategy?).

Learning Strategy Beliefs

Participants rated the efficacy of blocked and interleaved practices to learn painting styles on a 6-point rating scale[1] (1: extremely ineffective to 6: extremely effective). Two rating scales were presented, one for blocked and one for interleaved practice, in which participants were asked "How effective do you think the blocking (or interleaving) strategy is in helping you to learn the painting styles of artists?".

Classification Test I–II

Participants' classification performance was measured for each study phase. Test I involved two unseen paintings of each of the 12 artists from the first learning set. Test II involved three unseen paintings of each of the six artists from the second learning set. One additional painting per artist was added in the second test because our pilot study revealed that test II was easier than test I. In both tests, we showed participants one painting at a time and asked them which artist had created the respective artwork. Underneath the paintings, participants could select one option from the names of all artists and an "I don't know" option. Correct answers were not presented to participants and there were no time restrictions on the test. Classification performance was calculated using a similar scoring procedure for test I and test II. Each correct answer was worth one point and participants did not receive any points for incorrect and "I don't know" answers. In test I, participants could collect a maximum of 24 points (12 for painters studied with blocked practice and 12 for those studied with interleaved practice). In test II, participants could collect 18 points for either blocked or interleaved practice, depending on their strategy choice in the second study phase.

[1] In the preregistration form, this instrument was described as perceived effectiveness of learning strategies.

Visual Feedback Prompt

Participants in the VFP group were fed back their perceived effort and perceived learning in the form of individualized visual summaries, in which we presented two separate line graphs, one for perceived effort and one for perceived learning, using chart.js. Participants examined their subjective learning experiences across the different study units for each learning strategy (see Fig. 2). To help participants compare across time, study units were indicated as time-periods on the *x*-axis of the VFP graph: beginning (1st and 2nd units), middle (3rd and 4th units), and end (5th and 6th) units. To aid participants to reflect on the efficacy of learning strategies, we added four open questions to the visual summaries, prompting participants to evaluate the differences between learning strategies and the changes across time in their subjective learning experiences. These were:

1- On average, how did your perceived effort/perceived learning differ between blocked and interleaved practice?
2- How did your perceived effort/perceived learning change over the different blocked study units of the experiment? (e.g., went down, went up, or was stable)
3- How did your perceived effort/perceived learning change over the different interleaved study units of the experiment? (e.g., went down, went up, or was stable)
4- Why do you think your perceived effort/perceived learning changed (or did not change) and based on that information; which strategy do you think is more beneficial for learning the painting styles?

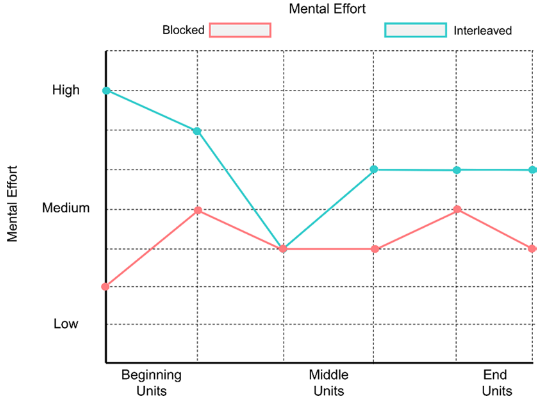


Fig. 2 An example of a VFP (of perceived effort) from one of the participants

Students' Evaluations of the VFP

Students' reactions to the VFP were obtained with an additional open question (i.e., Could you tell us: How did the visual summary of your mental effort and likelihood of recognizing the paintings of artists help you in choosing learning strategies?).

Procedure

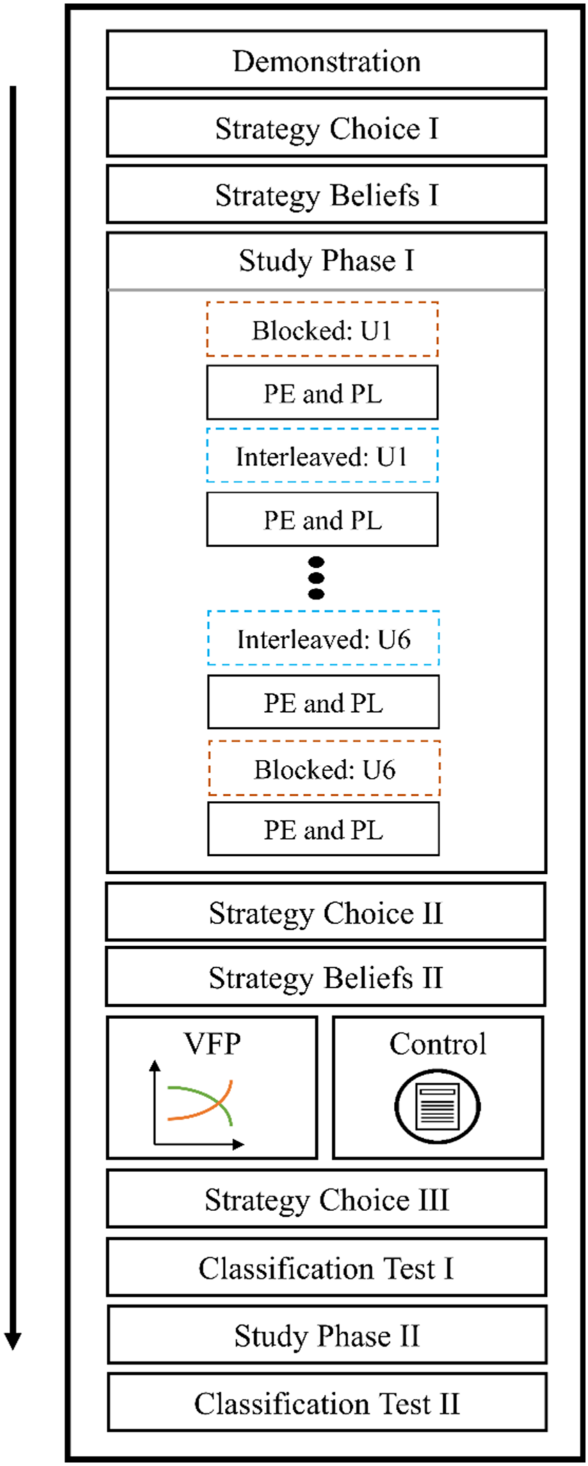
We designed the experiment in the Qualtrics (https://www.qualtrics.com/) survey software, and participants received a link to participate through the Prolific online recruitment service. Participants were instructed to allocate approximately 45 min to the study and complete the experiment without any interruption. Figure 3 displays the procedure.

Central to this study is the contrast between learning through blocked and interleaved practice. Thus, we first explained to participants how the exemplars of the same category can be grouped (i.e., blocked practice) or mixed between different categories (i.e., interleaved practice). We checked participants' understanding of these two learning strategies through two multiple-choice questions, in which participants were shown several study sequences and asked to identify whether these represented blocked or interleaved practice. We notified participants when their answer was correct and asked them to continue to the next page. For incorrect answers, we provided participants the correct answer with an explanation about why their answer was incorrect. As the next step, we showed participants three sample questions, which were similar to the questions asked in the classification tests. Then, participants made their first strategy choice and reported their learning strategy beliefs for the first time.

Subsequently, study phase I took place. In this phase, participants learned the painting styles of artists using blocked and interleaved practice. Participants studied the paintings in units following this study sequence: B-I-I-B-B-I-I-B-B-I-I-B, where B refers to blocked and I refers to interleaved units (Kornell & Bjork, 2008). To prevent order effects, we counterbalanced the order of which artist belongs to which strategy-unit sets using a Latin square design, resulting in 12 different strategy-unit sets that contain six blocked and interleaved units. Each painting was presented as follows: first, a fixation cross appeared at the center of the screen for 1 s, and then the painting, with the artist's last name above for 3 s. The order of the paintings presented in each unit was randomized per participant. At the end of each unit, participants reported their perceived effort and perceived learning. After they finished all units, participants made their second strategy choice and reported their strategy beliefs for the second time.

After study phase I, participants were randomly assigned to the VFP or control condition. In the VFP condition, participants inspected the visual summary of their subjective learning experiences and answered the prompt questions. Meanwhile, participants in the control condition read an article about the Internet obtained from Butler (2010). Afterwards, all participants made their final strategy choice (either blocked or interleaved practice). Participants were informed that they would have to study the painting styles of new artists with the strategy they selected. After this final strategy choice, participants' classification performance was measured in Test I.

Fig. 3 Procedure. Note: U, strategy units; PE, perceived effort; PL, perceived learning; VFP, visual feedback prompt



Next, study phase II took place, where participants studied the painting styles of new artists with the strategy they chose. The second study phase consisted of six units (BBBBBB or IIIIII). In this phase, participants did not rate their perceived effort and perceived learning to keep the experiment length manageable. After participants studied all units, they engaged in a 30-s distractor task to clear working memory (i.e., counting backwards by three from a three-digit number), and then their recognition performance was measured in Test II. Finally, participants shared their opinions about the VFP, completed the demographics questionnaires, and were provided information about the efficacy of blocked and interleaved practice in different learning contexts.

Results

Classification Performance

A paired sample *t*-test revealed that interleaved practice ($M = 5.95$, $SD = 3.55$) resulted in better classification performance than blocked practice ($M = 3.11$, $SD = 2.54$) in Test I, $t(149) = 9.35$, $p < 0.001$, $d = 0.76$. Supporting to this interleaving effect, an independent sample *t*-test further revealed that participants who chose interleaved practice to study novel materials ($M = 12.85$; $SD = 4.36$) outperformed those who chose blocked practice ($M = 10.04$, $SD = 4.61$) in Test-II, $t(148) = -3.73$, $p < 0.001$, $d = 0.61$.

Study Experiences as a Function of Learning Strategies and Time

To address the first research question, we examined how subjective learning experiences vary between learning strategies and across time using a linear mixed model (LMM) approach with the R (version 4.1.0) package lme4 (Bates et al., 2015). We created two separate models: One with perceived effort and one with perceived learning as the outcome measures. The fixed effects were time, as indicated by the study units, and learning strategies. We specified participants as a random effect (i.e., taking into account the random variability of participants in responding to our stimuli) and participants by learning strategies as a random slope (i.e., taking into account that the relations between our fixed effect and outcome measure could vary randomly in each condition).

Perceived Effort We observed a significant main effect of learning strategies: perceived effort was significantly higher for interleaved practice than for blocked practice, $F(1, 289) = 380.39$, $p < 0.001$. Additionally, there was a main effect of time, $F(1, 1498) = 121.35$, $p < 0.001$. However, as indicated in Fig. 4a, the main effect of time appeared to be driven by the strategy × time interaction, $F(1, 1498) = 135.22$, $p < 0.001$, which indicated that perceived effort decreased over time for interleaved practice, but not for blocked practice.

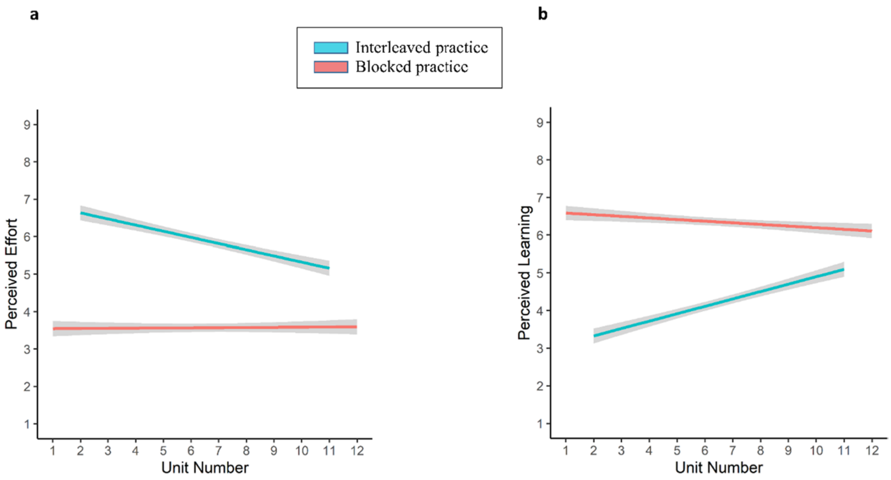


Fig. 4 Changes in perceived effort and perceived learning across time per strategy. **a** Changes in perceived effort. **b** Changes in perceived learning

Perceived Learning We observed a significant main effect of learning strategies: perceived learning was significantly higher for blocked practice than for interleaved practice, $F(1, 332) = 495.16$, $p < 0.001$. Furthermore, there was a significant main effect of time, $F(1, 1498) = 106.55$, $p < 0.001$. However, as indicated in Fig. 4b, the main effect of time again appeared to be driven by the strategy × time interaction, which indicated that perceived learning increased over time for interleaved practice, but not for blocked practice, $F(1, 1498) = 260.81$, $p < 0.001$.

Associations Between Perceived Effort, Perceived Learning, and Strategy Decisions

To address RQ-2, we first examined the global relations between perceived effort and perceived learning using LMM approach. Perceived effort was a fixed effect and perceived learning was the outcome measure. We specified participants as a random intercept and participants by learning strategies as a random slope.

Then, we examined the associations between perceived effort, perceived learning, and learning strategy decisions. Here, we argued that the temporal changes in subjective experiences drive learning strategy decisions. For this reason, we incorporated the time aspect into our analytic approach: We tested whether temporal changes in perceived learning would mediate the effect of temporal changes in perceived effort on learning strategy decisions. To account for temporal changes, we estimated each participant's linear change in perceived effort and perceived learning over time by extracting the regression slopes of these variables for each participant (Lorch & Myers, 1990). A positive slope would then indicate that perceived effort/learning increased over time and a negative slope would indicate that perceived effort/learning decreased over time for a particular participant. These changes of effort and learning per participant became the predictors in a mediation model for each learning strategy (Fig. 5): The independent

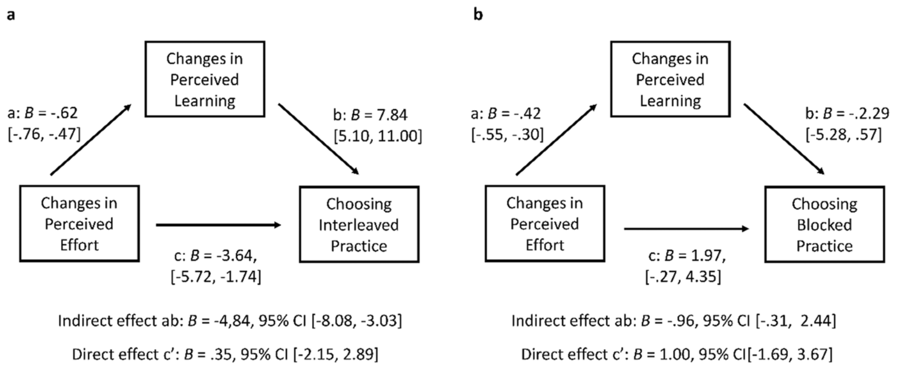


Fig. 5 Proposed mediation model for the relations between changes in perceived effort, perceived learning, and learning strategy choices. **a** Mediation model for choosing interleaved practice. **b** Mediation model for choosing blocked practice

variable was the change in perceived effort, and the mediator variable was the change in perceived learning. The outcome variable was the second strategy choice, and we entered the first strategy choice as a covariate to the models.

Perceived Effort and Perceived Learning: Global Associations

The results revealed that perceived effort was significantly and negatively associated with perceived learning, $B = -0.60$, $SE = 0.02$, $t(1455) = -30.69$, $p < 0.001$.

Perceived Effort, Perceived Learning, and Strategy Decisions Across Time

The first model examined the likelihood that students selected interleaved practice based on how their subjective experiences with this strategy changed across time. We found that students were more likely to select interleaved practice when their perceived effort decreased across time (path c, total path), $B = -3.64$, 95% *CI* $[-5.72, -1.74]$. Consistent with the global relations, students' perceived learning increased when their perceived effort decreased (path a), $B = -0.62$, 95% *CI* $[-0.76, -0.47]$. When perceived learning increased, students were more likely to choose interleaved practice (path b), $B = 7.84$, 95%, *CI* [5.10, 11.00], indirect effect $= -4.84$, 95% *CI* $[-8.08, -3.03]$. Notably, after controlling for perceived learning, the changes in perceived effort no longer predicted the likelihood that students selected interleaved practice (path c'), $B = 0.35$, 95% *CI* $[-2.15, 2.89]$, suggesting a full mediation.

The second model examined the likelihood that students selected blocked practice based on how their subjective experiences with this strategy changed across time. We found that the changes in perceived effort did not predict the likelihood that students selected blocked practice, $B = 1.97$, 95% *CI* $[-0.27, 4.35]$. Yet, consistent with the global relations, perceived learning increased when perceived effort decreased, $B = -0.42$, 95% *CI* $[-0.55, -0.30]$. However, the changes in perceived learning did not predict the likelihood that students selected blocked practice, $B = -2.29$, 95%

CI [−5.28, 0.57]. Also, the direct ($B = 1.00$, 95% *CI* [−1.69, 3.67]) and the indirect effect ($B = 0.96$, 95% *CI* [−0.31, 2.44]) were non-significant.

Strategy Decisions and the Impact of the VFP

As part of RQ-3, we first examined the strategy decisions in each time point. Before the study phase, only 13% of the participants reported using interleaved practice and 87% reported using blocked practice during their independent study time. After study phase I, 34% of the participants reported that they would use interleaved practice in a similar learning task, and 66% stated that they would prefer blocked practice. Finally, 40% of the participants chose interleaved practice and 60% chose blocked practice to study novel painting styles in study phase II.

A Cochran's Q test further revealed that strategy decisions to use interleaved practice significantly increased over time, $\chi^2(2) = 43.531$, $p < 0.001$. Post-hoc McNemar's tests with Bonferroni adjusted alpha level of 0.016 revealed that students increased their use of interleaved practice after study phase I, $\chi^2(1) = 18.481$, $p < 0.001$, but they did not further increase this after our treatment, $\chi^2(1)$, $p = 0.022$. A chi-square test of independence further indicated that the number of choices for interleaved practice did not significantly differ between the VFP and control group, $\chi^2(1) = 2.151$, $p = 0.142$.

Learning Strategy Belief Changes

Given that students who chose different learning strategies might show different patterns of belief change, we performed two separate 2 (Time; pre- versus post-study) × 2 (Strategy beliefs; blocked or interleaved) within-subjects ANOVAs; one for students who chose blocked practice and for those who chose interleaved practice.

For participants who chose blocked practice, there was no main effect of time, $F(1,89) = 2.71$, $p > 0.05$, $\eta p^2 = 0.03$, but the main effect of strategy beliefs was significant, $F(1, 89) = 254.07$, $p < 0.001$, $\eta p^2 = 0.74$. Importantly, we found a significant time × strategy belief interaction, $F(1, 89) = 66.71$, $p < 0.001$, $\eta p^2 = 0.43$. Pairwise comparisons revealed that efficacy beliefs for blocked practice increased over time ($M_{\text{pre-study}} = 4.42$, $SD_{pre\text{-}study} = 0.79$; $M_{\text{post-study}} = 4.99$, $SD_{post\text{-}study} = 0.63$, $t(89) = -6.77$, $p < 0.001$); whereas, efficacy beliefs for interleaved practice decreased ($M_{\text{pre-study}} = 3.59$, $SD_{pre\text{-}study} = 0.89$; $M_{\text{post-study}} = 2.80$, $SD_{post\text{-}study} = 0.99$, $t(89) = 6.27$, $p < 0.001$).

For participants who chose interleaved practice, there were no main effects of strategy beliefs and no main effect of time. However, there was a significant time × strategy belief interaction, $F(1,59) = 68.174$, $p < 0.001$, $\eta p^2 = 0.54$. Pairwise comparisons revealed that strategy beliefs for blocked practice decreased over time ($M_{\text{pre-study}} = 4.50$, $SD_{pre\text{-}study} = 0.73$; $M_{\text{post-study}} = 3.58$, $SD_{post\text{-}study} = 1.05$, $t(59) = 6.89$, $p < 0.001$); whereas strategy beliefs for interleaved practice increased ($M_{\text{pre-study}} = 3.75$, $SD_{pre\text{-}study} = 0.90$; $M_{\text{post-study}} = 4.70$, $SD_{post\text{-}study} = 0.83$, $t(59) = -7.50$, $p < 0.001$). These changes were quite substantial: At the pre-study, efficacy beliefs for blocked practice were significantly higher than for interleaved practice, $t(59) = 5.01$, $p < 0.001$. At the post-study, however, efficacy beliefs were significantly higher for interleaved practice than for blocked practice, $t(59) = -6.39$, $p < 0.001$.

Qualitative Results

We applied template analysis (King, 2004) — a form of thematic analysis — to explore students' beliefs and perceptions about blocked and interleaved practice (RQ 4) and to explore how they experienced and regulated their invested effort in learning (RQ 5). We chose this analytical procedure because template analysis would offer us the flexibility to identify all important themes relevant to our research questions. In template analysis, researchers analyze the qualitative data regarding underlying and recurring themes in participants' responses (King, 2012). This technique entails that a succession of coding templates is developed through an iterative process, where templates are continuously refined and adapted (Brooks et al., 2015). For an elaborate description about when and how to use template analysis, see Brooks et al. (2015). We applied this procedure to students' responses, on the open questions about learning strategy choices and the VFP. We approached these responses from the lens of the triangular association between perceived effort, perceived learning, and learning strategy choices.

The coding procedure was as follows. Initially, we divided students' responses into three datasets (25%, 25%, and 50%, respectively). The first and the last author open coded the first dataset independently and then created the initial template together. The first author applied this template to the rest of the responses while s/he continuously revised the initial template. Then, the first and the last author together reviewed this template by comparing their codings. At this stage, we increased reliability through an additional, blind coding. The third author, who was blind to the templates and students' responses, applied the reviewed template to the first and second datasets. After this round of coding, the first, the third, and the last author together evaluated any discrepancies between the first and third authors' templates, made minor adaptations where needed, and developed the final template. The final template was applied to the third dataset (50% of the responses). An overview of the main and sub-themes can be found in the Appendix.

Factors That Inform Learning Strategy Decisions

In what follows we will describe the factors that students mentioned in each strategy decision.

Strategy Decisions: Before Study Phase I

Prior beliefs and memories played an important role in how participants assessed blocked and interleaved practice before study phase I. These cues informed participants about the costs and benefits of learning strategies. Participants also described their study habits and metacognitive knowledge as influencing their strategy decisions. In these occasions, participants chose the learning strategy they generally use or think is most effective.

Focusing Attention and Monitoring Learning Optimizing attentional and metacognitive processes were two primary objectives that participants mentioned when choosing their preferred learning strategy. That is, participants compared the learning strategies based on how easily and how effectively they could "focus on each topic" (participant 46) and "keep track of what [they] learned" (participant 133). Participants who chose blocked practice showed a strong preference for the "one thing at a time" (participant 70) principle. In contrast, interleaved practice was mentioned to help participants stay "alert and aware" (participant 8).

Habits, Authenticity, and Metacognitive Knowledge We further observed that participants were inclined to use the strategy they perceived as more authentic. For example, participants chose the strategy that "flows more naturally" (participant 42) and they generally apply at school. Of interest, both strategies were mentioned as being used at university. In rare occasions, participants knew that interleaved practice is generally a more effective strategy than blocked practice. These participants chose interleaved practice.

Strategy Decisions: After Study Phase I

After study phase I, participants relied less on their prior experiences. Instead, they tuned into their on-task experiences generated by blocked and interleaved practice during the study phase. Using these experiences, participants contrasted learning strategies with regard to perceived costs and benefits of learning strategies.

Finding Similarities or Differences Participants compared blocked and interleaved practice based on how and how easily they could study the painting styles. However, they differed in describing how the strategies helped them to encode information. Participants who chose blocked practice mentioned that blocked practice helped them to "see similarities between paintings" (participant 46) and "identify common characteristics" (participant 18) within an artist's painting style. Others chose interleaved practice because they could "compare the different painting styles" (participant 19) and "understand subtle differences" between the painting styles of different artists. In both cases, participants were sensitive to the ease that they experienced while studying the painting styles; participants who prefer interleaved practice perceived interleaving as easier and vice versa.

Retrieval Processes In addition to encoding processes, learning strategy choices were affected by the outcomes of retrieval processes. That is, participants contrasted learning strategies based on whether or how easily they could retrieve the target information. For example, participants described using interleaved practice because they forgot the earlier painting styles studied with blocked practice. As mentioned by one participant: “The earlier blocking images won’t be as fresh in my mind as the later ones so there is less chance of me remembering those…” (participant 20).

Continued Preferences Prior preferences remained a salient factor that influenced learning strategy choices, with participants ignoring their on-task experiences and adhering to their study habits. In relation to this, participants also showed strong preferences to focus their attention on one subject at a time.

Strategy Decisions: After the VFP

This strategy decision took place after participants had either inspected the VFP or read the control text. During this decision, several themes mentioned above were repeated. We report only the novel themes below.

VFP: the Good and Bad The VFP contributed to the use of both blocked and interleaved practice. On the one hand, through the VFP, participants recognized temporal improvements in their subjective experiences, associated with interleaved practice. As mentioned by one participant:

> With the summary, I believe that at first, I would find it difficult to recognize the paintings but I will gradually get better […] I would better retain the information with interleaving (participant 90).

On the other hand, the VFP also reinforced the inaccurate monitoring of effort and learning, such that blocked practice was preferred because “this strategy needed less effort” (participant 77) and “the likelihood of learning was relatively higher” (participant 76) than with interleaved practice.

Use of the VFP Information in Learning Strategy Decisions

Understanding the Visual Summaries

For the VFP to fulfill its purpose, participants should understand the information presented in the line graphs. We examined this precondition by analyzing the correspondence between participants’ responses to the first three prompt questions and their actual ratings of mental effort and JOLs. That is, the three prompt questions were analyzed in terms of how accurately they represented the actual ratings across time of mental effort and JOLs. For example, when a participant mentioned “my effort decreased for interleaved practice,” this was considered high correspondence if the line graphs showed an actual decrease. For this purpose, the first author scored each participant on a scale from 0 to 2 (0, low correspondence; 1, partial correspondence; 2, high correspondence). Then, the third author, independently, scored 30% of the data. The interrater reliability was good, and the intraclass correlation coefficient = 0.89.

Effort Monitoring

Misinterpretation of Effort In monitoring effort, we observed that participants were vulnerable to misinterpretation of effort: High effort, associated with interleaved practice, indicated poor learning; whereas, low effort, associated with blocked practice, indicated high learning. Misinterpretation of effort led participants to choose the less effortful, but also less effective strategy, blocked practice:

I think blocking is a more effective strategy as it takes less mental effort. (participant 64).

Embracing the Effort Participants, however, could overcome this misinterpretation of effort, especially when they recognized that interleaved practice led to better learning than blocked practice. This interleaving effect became more salient to participants during the later course of the experiment. In this situation, high effort no longer signaled low learning but a price to be paid for successful learning. When effort was embraced, participants chose interleaved practice:

> I think the interleaving got easier over time because I'd learned a bit about the paintings. It took more effort than the blocking but this is probably a good thing as it meant that I was more engaged… (participant 121).

Effort Regulation

Data-driven Regulation When regulating effort, participants described being data-driven, they put in effort as much as a specific painting-unit called for (Koriat et al., 2014). In blocked practice, for example, participants experienced effort as a result of the "unique details in painting styles" (participant 50). In interleaved practice, participants experienced effort related to the number of to-be studied painting styles within a unit and how many times they studied the units.

Goal-Driven Effort Regulation A few participants, however, described being goal-driven in their effort regulation (Koriat et al., 2014), they invested effort in a top-down manner to maximize their learning:

> It [mental effort] did not really change because I honestly put an equal effort into studying the paintings throughout the study (participant 54).

We observed that participants could adopt a goal-driven approach when they noticed a shortcoming in their learning. For example, participants who noticed that they were unable to recall the previous painting styles, which had been studied with blocked practice, reported putting more effort into the blocked painting-units in the next phase.

Students' Evaluations of the VFP

We asked participants how they incorporated the VFP into their strategy decisions. Their answers revealed the role that the VFP played (or did not play) in learning strategy decisions (Table 1).

The VFP Changed My Decision We observed that the VFP interacted with learning strategy choices, by changing students' decisions. For example, participants who initially chose blocked practice changed their minds to use interleaved practice after they inspected the VFP:

> I chose completely based on the visual summary because it seemed to show that I was feeling better using the interleaving so I used that even though I previously thought that blocking was the best way for me to learn (participant 4).

Confirming Beliefs In addition to changing strategy decisions, the VFP led to confident decision-making. Participants mentioned that the VFP confirmed their beliefs and increased their confidence in the decision they made. Here, however, the VFP may act as a double-edged sword. On the one hand, the VFP may encourage students to choose the more effortful but effective learning strategy by endorsing their reasoning about the efficacy of interleaved practice: in the long run, interleaved practice costs as much effort as blocked practice but leads to higher learning:

> I felt that I already knew which strategy I wanted to use (interleaving), but it showed me that as the rounds progressed, I was starting to find it easier. It reinforced to me that it was working and that interleaving would allow me to be more likely to recognize a painting (participant 85).

The VFP Did Not Help Finally, several participants claimed that the VFP was not helpful when choosing learning strategies. These participants carried strong preferences toward a learning strategy and claimed that they did not need the VFP when making their strategy decision.

Discussion

This mixed-method study investigated how students utilize their subjective experiences of effort and learning, associated with (in)effective learning strategies, to make learning strategy decisions. Furthermore, we tested whether students can be supported to make effective strategy decisions through a metacognitive prompt that aims to overcome the misleading influence of immediate study experiences. In a category learning task, students learned about various painting styles through blocked and interleaved practice, rated their perceived effort and perceived learning, and chose interleaved or blocked practice to study novel materials. To promote the use of interleaved practice, we provided half of the students with a metacognitive prompt (VFP). This metacognitive prompt showed students how their subjective learning experiences changed across time and induced reflections about the triangle between perceived effort, perceived learning, and the efficacy of learning strategies.

Our findings showed that interleaved practice improved category learning beyond blocked practice, and students who chose interleaved practice outperformed others who chose blocked practice. Moreover, study experiences with interleaved practice improved across time: Students' perceived effort decreased while their perceived learning increased. Furthermore, this improvement resulted in more students choosing interleaved practice, though the prevalent strategy choice was still blocked practice. We found that students chose blocked practice due to several reasons. Quantitative findings revealed that students monitored the effect of their effort and learning inaccurately, such that they associated the effort demands of interleaved practice with ineffective learning. Perceived ineffective learning, in turn, prevented students from choosing interleaved practice. Complementing these results, qualitative findings revealed that students chose blocked practice despite the improvements in their study experiences with interleaved practice. This preference was stronger when students were driven by their study habits or their study experiences were still more favorable with blocked practice.

As for our intervention, we found that the VFP did not improve the use of interleaved practice. However, as revealed by the qualitative findings, the VFP increased students' confidence in their strategy choices. Finally, the present study revealed insight into students' perceptions of blocked and interleaved practice, and how they monitor and regulate their effort while executing these strategies. Students expressed a strong preference toward blocked practice as they aimed to optimize their attentional processes by focusing on one-subject-at-a time. They also showed a great diversity in their effort monitoring and regulation (Table 2): While the effort induced by interleaved practice could be embraced by students, it could also be misinterpreted as low learning.

Subjective Learning Experiences Across Time

Consistent with previous studies (Kirk-Johnson et al., 2019), we found that students, on average, experienced higher mental effort with interleaved practice than with blocked practice, and their perceived learning was higher for the blocked painting styles than for interleaved painting styles, confirming our first hypothesis. Extending these findings, we further found that subjective learning experiences with interleaved practice, but not with blocked practice, improved across time: for interleaved practice, we observed a significant decrease in students' perceived effort and a significant increase in their perceived learning. For blocked practice, students' perceived effort and perceived learning remained stable. Qualitative data suggested that perceived effort for interleaved practice decreased across time because students' task experience increased, indicating that perceived effort interacts with task familiarity (Andersen et al., 2018). In addition, students described that interleaved practice became easier due to the distributed presentation of painting styles: recognizing painting styles was easier after "each repetition" and their learning of the painting styles improved. Arguably, their increased learning of the painting styles through interleaved practice at the earlier stages of the study lowered the mental effort they experienced at the later stages. Together, these findings extend our understanding of desirable difficulties (Bjork & Bjork, 2011), by showing that desirable difficulties are not constantly difficult for students, as the effort demand of interleaved practice decreased considerably even after one study session and students became aware of their learning gains.

Relations Between Subjective Learning Experiences and Strategy Decisions

Our findings partially supported the second hypothesis on the relations between perceived effort, perceived learning, and learning strategy decisions. First, consistent with previous findings (Baars et al., 2020), we found that students' perceived effort was negatively associated with their perceived learning, indicating that students regulated their effort in response to task demands (i.e., data-driven approach, Koriat et al., 2014). An important qualitative observation was that students could shift their effort regulation from a data-driven approach to goal-driven approach, which represents a strategic form of effort regulation (Koriat et al., 2014). Here, students exerted additional effort to increase their performance after they recognized a gap in their learning. This observation is important because previous studies found that students could adopt a goal-driven perspective in the presence of incentives (Koriat et al., 2014) or under time pressure (Ackerman, 2014). Our findings suggest that students can willfully adopt the goal-driven perspective without external encouragement.

Second, we found that for interleaved practice, but not blocked practice, changes in perceived learning mediated the effect of changes in perceived effort on strategy choice. That is, students experienced gains in learning when their perceived effort decreased. This increase in perceived learning, in turn, resulted in more choices for interleaved practice. Contrary to our hypothesis, however, changes in subjective experiences of effort and learning associated with blocked practice did not relate to students' learning strategy choices. The fact that study experiences with blocked practice remained stable can explain why changes in perceived effort and perceived learning did not relate to their strategy choices. Together, these findings echo those of Kirk-Johnson et al. (2019). Both studies suggest that students did not avoid interleaved practice because they wanted to minimize their effort investment. Instead, students were misled by their inaccurate monitoring of effort and learning and avoided interleaved practice because they think the higher effort does not lead to more learning. As we observed in the qualitative data, students were willing to *embrace the effort* induced by interleaved practice once they recognized that their effort paid off in terms of learning gains: These students chose interleaved practice even though it costs them higher effort than blocked practice.

Learning Strategy Choices and VFP

In terms of students' learning strategy choices (Table 3) across time, we found an increase in the use of interleaved practice after students applied both learning strategies and rated their subjective experiences of effort and learning repeatedly: the number of students who chose interleaved practice increased from 13 to 34% after the study phase. This finding is noteworthy because it is likely that explicit and repeated monitoring of perceived effort and perceived learning enhanced learning strategy decisions. The benefit of capitalizing on study experiences is that study experiences can be immediately available upon reflection, while other means, such as performance feedback, are only available after processing students' responses. Nevertheless, this interpretation must be approached with caution because we had no control condition to reveal the true effect of repeated monitoring of on-task experiences on learning strategy decisions.

Contrary to our expectations, we did not confirm that the VFP would improve the use of interleaved practice. On the one hand, the VFP may have fallen short because for many students, on-task experiences were still more pleasant for blocked practice than for interleaved practice, even at the later course of the study. For example, students mentioned using blocked practice because their perceived learning remained considerably higher than their perceived learning with interleaved practice, even though they acknowledged the improvements in the latter. On the other hand, the VFP may also have fallen short because students, especially those who chose interleaved practice, might have already updated their knowledge about learning strategies, prior to inspecting the VFP. Supporting this possibility, we found that students changed their strategy beliefs substantially, immediately after the study phase. Thereby, the VFP created no additional benefit on top of that.

Nevertheless, qualitative results also revealed an interesting function of the VFP. Students' responses implied that the VFP influenced their strategy decisions qualitatively: It did not change their decisions but confirmed their subjective experiences and their strategy decisions. This finding indicates that the VFP might have been insufficient to alter learning strategy decisions due to confirmation bias. Confirmation bias suggests that individuals may select and interpret new information in a way that is consistent with their earlier thoughts and choices (Jones & Sugden, 2001). Students might have disregarded the improvement in their study experiences for interleaved practice but focused on the information that blocked practice cost less effort and offered higher learning.

Factors that Influence Learning Strategy Choices: Student Perceptions About Blocked and Interleaved Practice

We identified a number of factors that motivated students to choose blocked or interleaved practice. In general, students made their strategy decision by comparing the perceived cost (the effort) and perceived benefits (the utility) of learning strategies. Before the study phase, prior beliefs and memories informed students about the cost and benefits of learning strategies. We observed that students tend to believe blocked practice would help them focus better and therefore choose this strategy to optimize their learning. Students might have shown this preference as a form of goal shielding (i.e., focusing attention on one goal while inhibiting alternative goals), a coping strategy that individuals might employ when pursuing multiple goals (Orehek & Vazeou-Nieuwenhuis, 2013). Interleaved practice, which is characterized by studying exemplars of various categories, might be perceived as pursuing multiple competing goals and multitasking (Kung & Scholer, 2020). In addition to attentional processes, we found that students used blocked and interleaved practice as a monitoring tool that helped them to diagnose their understanding and track their overall study progress. This finding is surprising because we conceptualized blocked and interleaved practice as a learning strategy, which is different from monitoring: learning strategies serve to maximize learning while monitoring strategies serve to assess learning. Finally, the fact that just a few students knew interleaved practice is a better strategy than blocked practice at the start of the study indicates that most students lack metacognitive knowledge about learning strategies.

Our study also corresponds with Koriat's findings (1997), indicating that subjective on-task experiences can override the influence of prior beliefs and memories on monitoring judgments and self-control. Consistent with this view, our study showed that during the study, phase students shifted their focus from their prior beliefs and memories to their subjective, on-task, learning experiences with blocked and interleaved practice. Here, students tuned into the costs and benefits of learning strategies during information encoding (e.g., ease to detect differences between painting styles) and/or information retrieval (e.g., ease to remember previously studied painting styles), though their prior beliefs could still play a role in their strategy decisions if those beliefs were deeply rooted. Together, these findings can explain why minimal strategy instructions are inadequate to improve learning strategy decisions. Possibly, subjective experiences of effort and learning that arise during strategy execution provide students a highly accessible and salient cue that students cannot easily rule out. As students often monitor their effort and learning inaccurately, they chose the strategy that is less effective.

Limitations and Future Studies

The present study has several limitations. First, we did not examine students' learning strategy decisions in authentic learning situations. In authentic learning situations, learning strategy decisions can become high-stakes decisions, since students significantly increase their study time closer to the exam period (Blasiman et al., 2017). In this study, however, learning strategy decisions were relatively low-stake decisions since there were no significant consequences for students. Arguably, during high-stake decisions, students may rely less or differently on their on-task experiences and weigh the relative importance of cues differently. In a similar vein, individual differences in motivation (e.g., goals) or personality traits (e.g., conscientiousness) can play a bigger role in students' willingness to change their usual way of studying. For example, under time pressure, some students (e.g., students who aim for pass) might be less willing to apply interleaved practice than others (e.g., students who aim to enhance their knowledge) even though this novel strategy seems promising. We encourage future studies to examine how students make learning strategy decisions in low- and high-stake situations.

The second limitation concerns our learning task. In this study, we focused on students' on-task experiences in category learning and characterized interleaved practice as a desirable difficulty (Bjork & Bjork, 2011). We chose a painting classification task to establish our paradigm because it has been previously shown to induce an interleaving effect. Our findings confirmed that interleaved practice resulted in better category learning, and students increased their use of interleaved practice. The generalizability of these findings, however, is currently limited. A recent meta-analysis showed that interleaved practice is most effective for learning visual naturalistic categories, such as painting styles and bird-species (Brunmair & Richter, 2019). But some recent studies also found that students benefit from interleaved practice when they engage in educationally more authentic, complex materials (Mielicki & Wiley, 2022; Samani & Pan, 2021). Using time recordings and difficulty ratings, these studies further indicated that students experience similar biases when learning complex materials. For example, in an introductory physics course, Samani & Pan (2021) found that students thought interleaved practice was more difficult than blocked practice. Their students also underappreciated the learning benefits of interleaved practice despite the improvements in their actual learning. We encourage future research to use more direct measures of effort and replicate the interleaving effect with more authentic materials.

The third limitation concerns our study design. In this study, all strategy choices took place within the same study session. There are a few caveats to this approach. For example, giving students an opportunity to repeat and reason their faulty beliefs might have strengthen their prevalence (Lewandowsky et al., 2012). Additionally, students may have recognized the true purpose of the study due to the repeatedly asked strategy questions, creating a so-called demand effect. However, this was probably not the case given that only a modest rate of students adopted interleaved practice and our instructions never disclosed information that could hint students to the effectiveness of learning strategies (e.g., by using neutral language and randomizing the order of the learning strategy choice questions). Unfortunately, it also remains unclear from this study that whether improvements in students' learning strategy decisions would be visible in a new study task after a delay. Finally, our findings suggest that our manipulation might have been more successful if we would have offered students more study sessions. Despite improvements, interleaved practice cost students higher effort than blocked practice, and perceived learning was still higher for blocked painting styles than for interleaved painting styles. After multiple study sessions, however, interleaved practice might offer students more favorable study experiences than blocked practice, and improvements in subjective learning experiences might become more salient to students in the VFP, which in turn, might contribute to their strategy decisions. Together, we encourage future studies to explore how on-task experiences with blocked and interleaved practice would change after multiple study sessions and whether those changes improve students' learning strategy choices.

Conclusion

To our knowledge, the present study was the first mixed-methods study to investigate (1) why students make poor strategy decisions in category learning tasks and (2) how to improve their strategy decisions. Overall, our study showed that students made poor strategy decisions due to their inaccurate monitoring of effort and learning. Nevertheless, students made better strategy choices across time and increased their use of interleaved practice after applying both strategies and monitoring their perceived effort and perceived learning repeatedly. However, students did not benefit from additional monitoring opportunity through a metacognitive prompt that induced self-analysis of subjective learning experiences across time. Qualitative findings revealed that prior beliefs and study habits may govern the initial strategy choices; however, on-task experiences can override the influence of these factors. Furthermore, students can exert strategic control over their on-task experiences.

Appendix

Table 1 Main categories of students' evaluations of VFP

Main code	Description	Example
VFP changed learning strategy decisions	Instances in which participants mentioned that VFP led them to use blocked or interleaved practice	"It made me change my mind to use [interleaved practice] instead of blocked practice. …I felt like it would be more challenging but ultimately helping me encode information more strongly"
VFP confirmed beliefs	Instances in which participants mentioned that VFP confirmed their feelings about learning strategies	"I already made my choice during the study, before seeing the visual summary … I was neat to see the summary though, as I could identify the reasons the curves went up or down"
VFP played no rolex	Instances in which participants mentioned that VFP played no role in their strategy decisions	"I don't necessarily think that it did. I already had a pretty strong feeling as to which strategy was working more for me"

Table 2 Main and sub-categories of students' effort monitoring and regulation

Main code	Sub code	Description	Example
Effort monitoring	Misinterpretation of effort	Instances in which participants associated high effort with low learning and low effort with high learning	"I think blocked practice worked better as it was easier and I think I got more information from it"
	Embracing effort	Instances in which participants showed willingness to invest the high effort caused by interleaved practice	"I think interleaving was a bit more effortful because I started to compare and analyze more as the learning went on. That is probably more beneficial to learning"
Effort regulation	Data-driven effort regulation	When students exerted effort as a result of task demands	"[Effort] was up and down because some painters had distinguishable painting styles"
	Goal-driven effort regulation	When students exerted effort in a top-down manner	"I honestly put an equal effort into studying the paintings"

Table 3 Main and sub-categories of students' learning strategy choices

Strategy choices	Main code	Sub-categories	Description	Example
Strategy choice I	Prior beliefs and memories	Focused attention	Instances in which participants referred to how they want to attend information to-be processed	"It is easier for me to concentrate on one thing at a time than multiple things at once"
		Monitoring learning	Instances in which participants referred to assessing knowledge and tracking study progress	"By using blocked practice, you are able to pinpoint more easily the areas in which you struggle more"
		Habits	Instances in which participants referred to their usual way of studying	"This is naturally what I do"
		Authenticity	Instances in which participants described the utility and relevance of learning strategies in real life	"Interleaved practice is also how we are tested in real-life"
		Metacognitive knowledge	Instances in which participants showed knowledge about the efficacy of learning strategies	"Interleaved practice is a more efficient strat-egy to remember things"
Strategy choice II	On-task experiences and Prior beliefs	Finding similarities	Instances in which participants referred to recognizing the similarities within (or between) artists' painting styles	"I am able to see similarities between paint-ings and pick up on the style more easily"
		Finding differences	Instances in which participants referred to recognizing the differences between (or within) artists' painting styles	"It gives you a chance to compare the different styles which makes it easier to identify"
		Retrieval attempts	Instances in which participants referred to recalling information through learning strategies	"I cannot remember the first and second artists because it was too long ago"
		Continued preferences	Instances in which participants referred to their study habits without mentioning their on-task experiences	"It is the one I am most familiar with"

Table 3 (continued)

Strategy choices	Main code	Sub-categories	Description	Example
Strategy choice III	The role of VFP	VFP as good	Instances when VFP led to the use of interleaved practice or reinforced participant decision to use interleaved practice	"After all graphs, my conclusion is that interleaved practice is more beneficial"
		VFP as bad	Instances when VFP led to the use of blocked practice or reinforced participant decision to use blocked practice	"I picked this strategy because my likelihood to learn was higher (for blocked practice)"

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Declarations

Conflict of Interest The authors declare no competing interests.

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