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REVIEW ARTICLE

Worth the Effort: the Start and Stick to Desirable Difficulties (S2D2) Framework

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Abstract

Desirable difficulties are learning conditions that are often experienced as effortful, but have a positive effect on learning results and transfer of knowledge and skills (Bjork & Bjork, 2011; Bjork, 1994). Learners often do not appreciate the beneficial effects of desirable difficulties, and the negative experiences of high effort and perceived low learning make them resistant to engage in desirable difficulties (Biwer et al., 2020a). This ultimately limits learning outcomes and academic achievement. With the increasing emphasis on self-regulation in education, characterized by higher learner agency and abundant choices in what, when, and how to study, the field of educational psychology is in need of theoretical and empirically testable assumptions that improve self-regulation in desirably difficult learning conditions with the aim to foster self-regulation abilities, learning outcomes, and academic achievement. Here, we present a framework that describes how to support self-regulation of effort when engaging in desirable difficulties: the "Start and Stick to Desirable Difficulties (S2D2)" framework. The framework builds on the Effort Monitoring and Regulation model (de Bruin et al., 2020). The aim of this framework is (1) to describe evidence for the central role of perceived effort and perceived learning in (dis)engagement in desirable difficulties, and (2) to review evidence on, and provide an agenda for research to improve learners' self-regulated use of desirable difficulties to help them start and persist when learning feels tough, but is actually effective.

Keywords Desirable difficulties · Effort monitoring · Effort regulation · Self-regulation · Learning strategies · Interventions

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"No pain, no gain" is an often-uttered phrase in sports, and increasingly in educational learning contexts (Metcalfe, 2011). The pain in such utterances refers to the effort that is experienced when engaging in exercise or in learning tasks that are typically unfavorable; those where experiences of fluency are scarce (Ackerman & Zalmanov, 2012). The underlying assumption of the "no pain, no gain" utterance is that without effort, no improvement in performance will be accomplished. In many learning contexts, indeed, the processing mechanisms that cause effort are the ones actually leading to more learning. This is the case when learning involves so-called desirable difficulties.

Desirable difficulties are defined as learning conditions that are (1) at the correct level of difficulty and enhance learning and chances of transfer to other contexts (i.e., high actual learning), and (2) at least initially, subjectively experienced as effortful (i.e., high perceived effort). Moreover, learners typically perceive desirable difficulties as contributing little to learning because of non-visible or delayed learning effects and/or high perceived effort (i.e., low perceived learning) (Bjork, 1994; Bjork & Bjork, 2011). For example, learners improve their retention in category learning when they interleave rather than block the order of their study materials (Birnbaum et al., 2013; Brunmair & Richter, 2019). Desirable difficulties also occur when learners test themselves after studying (i.e., retrieval practice, Roediger III & Karpicke, 2006). Learners often prefer restudying when in fact testing typically has a stronger long-term learning effect (Karpicke & Roediger, 2007). Other desirable difficulties include varying the contexts of practice, spaced learning of study materials, and self-explanation during learning (Bjork & Bjork, 2011). Even when learners are aware that interleaved practice and retrieval practice are effective, they are often unwilling to invest the necessary effort because the effort induced by the more effective strategies is notoriously higher (Karpicke et al., 2009) and because learners estimate that the learning effect will be small. To complicate matters further, the learning effects caused by desirable difficulties are typically not immediately noticeable, but only appear after a delay as in the case of retrieval practice, or they are difficult to discern as in the case of interleaved practice. Learners' erroneous interpretation of the limited effect of these strategies on their learning results further contributes to avoiding and disengaging prematurely from desirable difficulties (Biwer et al., 2020a). Not surprisingly, learners report low enjoyment in these kinds of learning circumstances (Baddeley & Longman, 1978).

The negative subjective experiences of perceived high effort and perceived low learning make learners particularly resistant to use and persist on desirable difficulties (Biwer et al., 2020b). This resistance ultimately has a detrimental effect on learning outcomes and academic achievement. Therefore, research is direly needed to understand how learners can overcome these misinterpretations and start and stick to desirable difficulties. Here, we present a framework to understand how to support self-regulation of effort when engaging in desirable difficulties; the "Start and Stick to Desirable Difficulties (S2D2)" framework. The framework builds on the processes and research questions described in the Effort Monitoring and Regulation (EMR) Model (de Bruin et al., 2020; see Fig. 1) but specifically focuses on how to support learners to self-regulate (dis)engagement in desirable difficulties. The EMR model finds its base in the Nelson and Narens model (Nelson, 1990; Nelson &

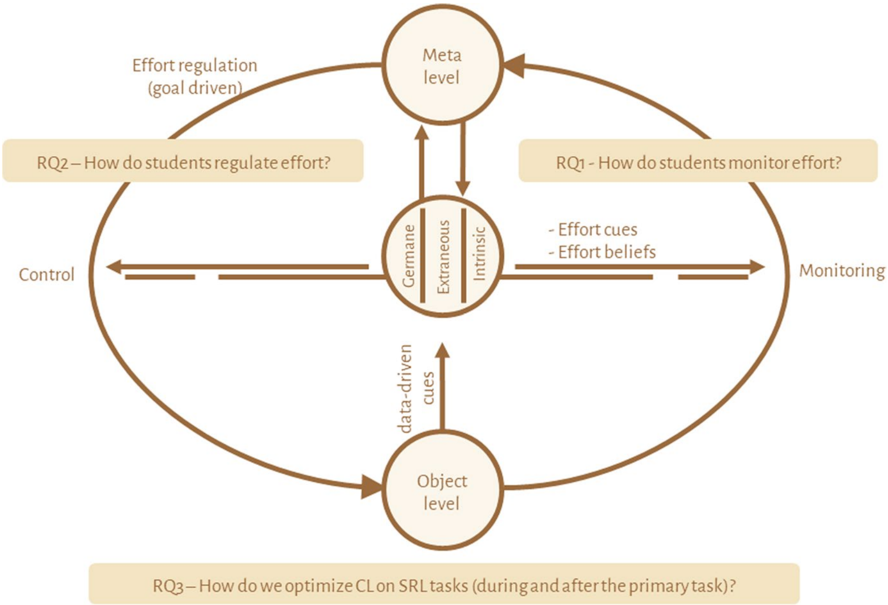


Fig. 1 Reused and adapted with permission—Integrating CLT and SRL theory: the Effort Monitoring and Regulation (EMR) Framework (De Bruin et al., 2020)

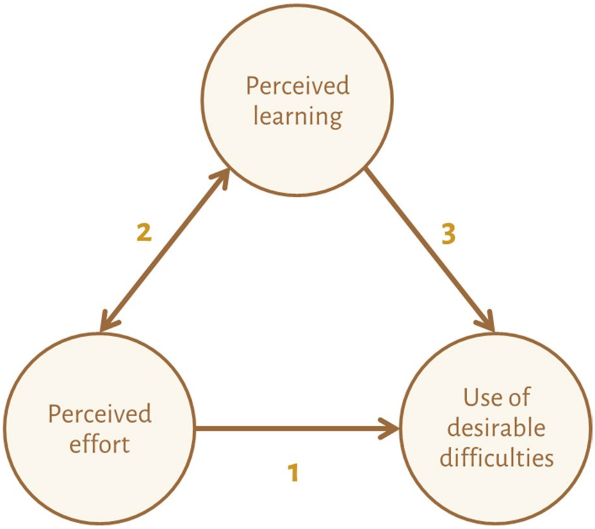
Narens, 1994), which describes how cycles of monitoring and regulation of learning characterize learning task engagement. Monitoring takes place by the learner evaluating what happens when engaging in the learning task. The result of monitoring is brought into the "metalevel." Control or regulation is then exerted to translate decisions from the metalevel to the learning task level (also termed "object level," see Fig. 1). The EMR model outlines how effort is used as a basis for monitoring and control of learning, and how effort needs to be managed in self-regulated learning environments. It shows that effort is used as a cue to monitor learning, but effort also needs to be regulated during learning. The current framework focuses on the first two research questions related to the EMR model on how students monitor (research question 1) and regulate (research question 2) effort.

The aim of this manuscript is twofold. First, to describe the central role of perceived effort and perceived learning in learners' self-regulated (dis)engagement in desirable difficulties. Second, to provide predictions that form a basis for intervention-based research to improve self-regulated use of desirable difficulties by shifting learners' experiences of effort and learning in order to help them start and persist when learning feels tough, but is actually effective. With the growing emphasis on self-regulated learning in education, characterized by higher learner agency and less teacher guidance, the field is in dire need of theoretical and empirically supported or testable assumptions on how to improve self-regulation towards desirably difficult learning conditions to foster self-regulatory abilities. Importantly, practicing desirably difficult strategies should benefit *everyone*, both learners who want to master a certain subject and learners whose main aim is to achieve a sufficient grade to pass a course as efficiently as possible. This benefit stems from the fact that for both types of learners, learning will take effort (Biwer et al., 2021). Thus, practicing effective learning strategies can be considered an optimal course of action since this approach would yield the most benefit (e.g., a higher likelihood to achieving mastery or a higher likelihood to pass a course, respectively) and therefore is an efficient allocation of resources. However, convincing all types of learners to use desirable difficulties is no easy feat as it will depend on finding the right combination of interventions at three levels: (1) by increasing learners' strategy knowledge about desirable difficulties and correcting some of their misconceptions about effective learning, (2) by adapting the instructional design at the learning task level to make the task feel less effortful, and/or (3) by providing the learner with self-regulation strategies (including motivational regulation strategies) that they can employ when needed.

We will first define the crucial terms used in this paper: effort regulation, effort monitoring/perceived effort, and perceived learning. Then, we will explain our assumption that perceived effort is a type of metacognitive judgment. Self-regulation of effort, hereafter referred to as "effort regulation," is defined as the conscious decision to invest or stop investing effort, the actual investment of, and the fluctuations in mental effort when engaging in a learning task. Effort regulation is measured behaviorally as decisions to start or stop applying a desirably difficult learning strategy, or as persisting to invest effort. Effort monitoring usually precedes effort regulation and entails all subjective experiences of effort that build up to and include an explicit rating of effort, such as learners' perception of the effort that they will put forth and/or the effort they have put forth. This concept is hereafter termed "perceived effort." Our conceptualization of perceived effort is based on the recent review paper by Scheiter et al. (2020), who indicated that ratings of experienced effort are in fact a type of metacognitive judgment that result from heuristic processing and are therefore prone to biases. That is, self-reports of effort through ratings on a Likert-type scale should not be viewed as objective reflections of effort based solely on the difficulty of a task. Instead, learners derive them dynamically through several sources of information such as their effort beliefs, prior task experience, current level of fatigue, interest in the task, and fluency of processing. As in the case of metacognitive judgments such as judgments of learning (de Bruin et al., 2017; Koriat, 1997), learners do not have direct access to the effort they actually expend and therefore have to infer their objective effort based on information sources typically termed "cues." These cues vary in how validly they reflect objective effort, with many of these cues being potentially low in validity. However, what cues learners actually use when rating effort and how these cues vary between learners and contexts has been hardly studied. The potential non-validity and biases in these cues ask for more attention in research.

The concept of perceived learning is defined as learners' monitoring judgments of their current level of learning. These judgments can be measured in many ways such as through Judgments of Learning (Nelson & Dunlosky, 1991), predictions of performance (van Loon et al., 2014), and feeling of knowing (FOK; Koriat, 1993). Within the realm of desirable difficulties, these monitoring judgments are usually made during encoding and before retrieval (e.g., when studying a learning task), but in the context of retrieval practice are also made post-retrieval.

Fig. 2 The possible relations between perceived effort, perceived learning, and learners' engagement in desirable difficulties



Relations Between Perceived Effort, Perceived Learning, and Use of Desirable Difficulties

We argue here that understanding and improving effort regulation in desirable difficulties critically hinges on the interrelations between perceived effort, perceived learning, and use of desirable difficulties (see Fig. 2). We propose three possible interrelations that act separately or jointly and give examples of contexts in which one, two, or all three modeled interrelations apply. We provide a description of self-regulated use of desirable difficulties in authentic self-study learning environments, where learner engagement and invested effort are not statically dependent on task complexity, but continuously and actively self-regulated based on learning context, learning task, and learner characteristics. Given the self-study context, the empirical focus is mainly on (older) adolescents and adult learners. We then synthesize findings from research that informs how to improve engagement in desirable difficulties. We posit that learners should be supported to experience the added value of effort and accept the high perceived effort, reduce or, alternatively, "silence" their perceived effort. We explain how future research should examine how training programs and instructional design can support learners to accept, reduce, or silence perceived effort.

Relation 1—Perceived Effort is Associated with the Use of Desirable Difficulties

Learners are known to interpret perceived effort as a motivational cost (Feldon et al., 2019) or as generally aversive (Inzlicht et al., 2018; Shenhav et al., 2017). That is, learners may interpret the effort they experience or have experienced before as a cost that negatively impacts their motivation to engage in a learning task, or specified to the current context: the use of desirable difficulties. This effort interpretation may occur as a pre-existing belief, unrelated to perceived learning (Feldon et al., 2019). It may also result from engaging in a learning task, as described below. Correlational research indicates that the experienced concept of cost is distinct from the expectancy factor of motivation (Dietrich et al., 2019; Perez et al., 2019). This implies that even separated from the perceived expectancy of a learning task, the cost learners perceive may impede their engagement in the task.

Why do the costs of effort learners perceive impede one's engagement in a task? According to the opportunity cost model (Kurzban et al., 2013), the experienced costs of effort invested in a task are weighed against alternative opportunities. For example, when a student needs to read a textbook chapter to prepare for an exam, they could read the chapter and then take the end-of-chapter practice test (a desirably difficult strategy) or read the chapter and then read the summary that a peer student gave them (an ineffective strategy). Having the latter, lower effort option as an opportunity increases the perceived costs of the desirably difficult strategy: taking the practice test. The *objective* benefit of taking the practice test is constant, yet it may feel *subjectively* higher when the student has the peer's summary available.

In the context of desirable difficulties, the negative effect of perceiving effort as costly or aversive was also observed in research by Hui and colleagues (2022). Here, learners' effort ratings directly predicted their use of the desirable difficulty retrieval practice, and perceived learning did not appear to play a role. Apparently, learners limited their effort regulation towards desirable difficulties because they experienced the costs of putting in effort as simply too high. The "effort as costly" belief then serves as a cue that dominates effort monitoring and impedes effort regulation. It should be mentioned that learners may experience other types of costs than effort costs when self-regulating their learning, such as emotional costs and costs related to loss of valued alternatives (Flake et al., 2015). How these other types of costs relate to effort costs and to the use of desirable difficulties, how these costs change over time, and how interventions can help learners manage perceptions of cost is an important avenue for future research (for a short scale, see Beymer et al., 2022).

Relation 2—Perceived Effort is Intricately Related to Perceived Learning

Although learning contexts exist where perceived effort is directly related to the willingness to engage in desirable difficulties as described in Relation 1, it is also often observed that learners relate their perceived effort to perceptions of their current level of learning. As evidence for the intricate relation between perceived effort and perceived learning, a recent meta-analysis (Baars et al., 2020) revealed that learners' effort ratings correlate negatively with judgments of their learning when engaging in a learning task ($r = -0.355$). The correlation was weaker for prospective than for retrospective judgments, and stronger for problem-solving than for paired associates tasks. This finding aligns with research showing that decisions about how learners invest effort are often made considering perceived effects on learning (Kirk-Johnson et al., 2019), and research showing that there is a negative relation between effort ratings and learners' self-efficacy (Likourezos & Kalyuga, 2017). The negative correlation between effort ratings and judgments of learning suggests that learners tend to apply a data-driven interpretation of effort (Koriat et al., 2014). In data-driven effort interpretations, learners apply the *easily-learned-easily-remembered* heuristic (Koriat, 2008) and view experiences of high effort as an indication of poor learning from the task and vice versa. Consequentially, experiences of high effort can lead to erroneous conclusions in the case of desirable difficulties where the "high effort-low learning" relation does not apply.

This interpretation of perceived effort may be biased due to learners' perceived fluency of processing (Reber & Greifeneder, 2017). Perceptions of fluency refer to the ease or difficulty with which a task is processed and, as such, describe a sheer subjective feeling (Reber & Greifeneder, 2017). What learners term "ease" can be interpreted as experiencing a greater sense of fluency, which they typically associate with more positive learning outcomes. If the concept of fluency plays a dominant role in how learners shape experiences of effort, then they will be reluctant to engage in desirable difficulties, as desirable difficulties are characterized by the opposite, that is, experiences of disfluency and difficulty. This was observed in a recent study by Onan and colleagues (2022). Students who reported ease of use or ease of retrieval as a basis for choosing a learning strategy indicated they chose the desirable difficulty of interleaving less often and were more inclined to use blocking as the preferred learning strategy. Note that some students reported higher fluency when using interleaving, stating that to them this desirable difficulty felt easier to use.

There is also evidence that the relation between perceived effort and perceived learning can be reversed and learners base their perceptions of effort on their experiences of learning (see the bidirectional arrow for Relation 2 in Fig. 2). Raaijmakers et al., (2017; Exp. 3) showed that when learners first received feedback about their learning before rating effort, they adapted their ensuing effort ratings in a data-driven manner: Effort ratings were lower when learning was seemingly successful and higher when learning was seemingly unsuccessful. Learners were provided no, positive, or negative feedback regardless of actual performance before rating their invested effort. The "day of the week task" they used is highly difficult to self-assess performance on, so learners accepted the feedback as real (Van Gog et al., 2012). Here, effort ratings were higher after negative feedback than after positive feedback indicating that post-task ratings of perceived invested effort are not neutral but can be influenced by external factors in a data-driven manner, in this case the feedback valence.

When learners assume a goal-driven approach, they judge that high effort is a positive sign of learning.[1] By setting a specific learning goal and continuously monitoring learning progress towards the goal, the negative interpretation of high effort as indicating low learning is disrupted. In the Baars et al. (2020) meta-analysis, the subset of studies where learners adopted a goal-driven interpretation of effort showed no negative correlation between effort and learning. Translated to the context of desirable difficulties, perceived effort is then positively valued against its perceived effect on learning and students experience but accept the effort: Higher effort

[1] This distinction is also termed passive load (load experienced bottom-up from the task) versus active load (load actively controlled and invested by the learner, Klepsch & Seufert, 2021).

then leads to higher perceived learning and more use of desirable difficulties. The Baars et al.'s (2020) meta-analysis shows that the goal-driven approach is less common among learners than the data-driven approach. All in all, experiences of effort are intricately related to experiences of learning, and biases in both types of experiences affect regulation of effort towards desirable difficulties.

If perceived effort and perceived learning are intricately related, what evidence is there that perceived effort affects actual use of desirable difficulties through its relation to perceived learning? Evidence for this relation comes in two forms. First, studies have provided evidence for a partial mediation model, where perceived effort plays both a direct and indirect role in explaining the use of desirable difficulties. This type of evidence comes from the same research by Hui and colleagues (2022) mentioned above. In this study, learners were provided individual performance feedback on their learning of human anatomy image-name pairs that indicated how much they learned both under restudy and retrieval practice conditions. Before feedback, learners' strategy decisions displayed evidence for the "effort is costly" belief, showing that learners' perceived effort was directly associated with their strategy decisions, but perceived learning did not play a role. After feedback, a partial mediation model was observed: Learners' strategy decisions were directly affected by effort ratings and indirectly through perceived learning. Apparently, once learners have a stronger base for their judgments of learning through performance feedback, they start relying on these judgments too when making learning strategy decisions. Note that effort interpretations were still negatively data-driven, so providing performance feedback did not necessarily mean that learners appreciated the positive effect of effort invested into desirable difficulties.

The second form is a recent example of evidence for a full mediation relation between perceived effort, perceived learning, and use of desirable difficulties in the research mentioned above by Onan and colleagues (2022), where learners studied painting styles of different artists in blocked and interleaved manners. Learners were required to monitor effort and learning when applying the two strategies, and later had to choose whether they wanted to study novel paintings in a blocked or interleaved manner. Perceived effort was higher and perceived learning was lower for interleaving than for blocking. These differences between blocking and interleaving decreased after experience with the strategies. The decrease in these differences was mostly due to the fact that perceived effort diminished and perceived learning increased for interleaving over time while ratings for blocking remained relatively stable. Moreover, the effect of this decrease in perceived effort on use of interleaving was mediated by the increase in perceived learning. Apparently, when learners' perceived effort for interleaving decreased through experience with this strategy, this was associated with an increase in perceived learning, which showed a positive association with choices for interleaving. This relation was, however, absent for blocking units, where perceived effort was lower and perceived learning was erroneously higher to begin with and changed less through experience. Potentially, familiarity with the strategies plays a role here. Since learners were more familiar with blocking, the experience with blocking in the current study had less of an effect on their ratings of effort and learning than the more novel experience with interleaving (Macaluso et al., 2022).

Relation 3—Perceived Learning Is Directly Related to the Use of Desirable Difficulties

There are circumstances when perceived effort does not play a role and use of desirable difficulties is related solely to perceived learning. One such situation is when the opposite of the "effort is costly" belief is at play, which can be termed the "extremely goal-driven" situation. This situation is much less observed in education, but happens when a task is highly important for a learner because of an important deadline, or because of high value or interest in the task, and learners disregard their perceptions of effort and base their effort regulation purely on expectations of perceived learning. Learners will even pull an "all-nighter" to achieve their goal. Flow-like experiences can also be interpreted as examples of the extremely goal-driven approach (Nakamura & Csikszentmihalyi, 2014) because under these circumstances perceptions of effort also appear to be silenced (Swann et al., 2016).

Alternatively, there are situations when learners are data-driven, have low perceptions of learning that are unrelated to their effort experiences, and are not inclined to use desirable difficulties. This situation occurs when the desirable difficulty does not seem to show an effect on learning. For example, when using retrieval practice, learning effects are not immediately visible but appear only after a delay (Karpicke & Roediger, 2008; Nunes & Karpicke, 2015). In this situation, learners' judgments of learning are opposite to their actual learning effects (Nunes & Karpicke, 2015). Learners are then unlikely to engage in retrieval practice but prefer restudying learning materials as restudy leads to the experience of immediate learning gains. Similar misinterpretations of perceived learning gains have been found for massed versus spaced practice (Logan et al., 2012), and blocked versus interleaved practice (Yan et al., 2016). The erroneous experience of low learning gains when engaging in desirable difficulties asks for dedicated research on effective interventions that can mend these experiences.

Improving Effort Monitoring and Regulation Towards Desirable Difficulties

The three relations described above together underline how monitoring and regulating effort and learning accurately are central to optimally engage in desirable difficulties and to increase learning outcomes. To achieve this, learners need to become aware of the actual value of effort and its positive effects on learning in desirable difficulty contexts. Put differently, learners should adopt a more goal-driven interpretation of effort. How this can be enabled is the topic of the remainder of this writing. Note that the goal is not only to decrease the effort. Effort put into desirable difficulties will often remain higher than effort put into ineffective strategies, even though this difference may become smaller after practice (Onan et al., 2022). The desirable difficulties usually remain more effortful because they generally require active, generative processing, thereby inducing more germane load to put in cognitive load theory terms (Sweller, 1988).

Relating these insights to the EMR framework (de Bruin et al., 2020), we posit that perceived effort is continuously experienced and invested effort is dynamically regulated by the learner, where task difficulty and perceived learning are important but potentially misleading cues learners use to regulate their effort. Perceived effort is usually viewed as not controllable by the learner, but how learners *interpret* the perceived effort is indeed controllable through reinterpretation or by reducing biased beliefs. Supporting learners through general training programs and instructional design to optimally deal with high perceived effort and low perceived learning during desirable difficulties is an important step towards effective regulation of effort and learning.

The insights described below integrate findings from research on instructional design and how experienced effort can be reduced, from research on the added value of effort, which describes when learners accept the high experienced effort, and from self-regulation research on how learners can become more goal-driven in their effort investments. In contrast to a recent review by Castro-Alonso and colleagues (2021), here, we do not refer to self-managing working memory load by self-generating visualizations or highlighting to signal important information. Instead, we focus on helping learners to (re)interpret their perceived effort and learning in such a way that would help them regulate their invested effort effectively. However, the effort reducing interventions at the task level show some overlap with the interventions described in Castro-Alonso et al. (2021) whenever these interventions also lead to reinterpreting perceived effort.

We then explicate a research agenda to further investigate several unanswered questions. To foreshadow, we argue that to improve effort regulation towards desirable difficulties, the typically high experienced effort should be accepted, reduced, or silenced (See Table 1). This can be achieved at three levels: (1) at the strategy level by educating learners about desirable difficulties, (2) at the task level by adapting the instructional design, or (3) at the learner level through (supported) self-regulation strategies including motivational regulation strategies. Finally, we describe the contexts in which effort monitoring is improved, but effort regulation still suffers. Note that interventions at the strategy level are mostly effective to get learners to *start* using desirable difficulties, whereas interventions at the task and learner level are relevant when learners have started using desirable difficulties and need to *stick to* using them. For sustainable internalization of desirably difficult learning strategies, a combined implementation of both start- and stick to-interventions is needed (Biwer et al., 2020b).

In all approaches described, perceived learning increases either because they are instructed about this or experience this (in the “Accept” approaches) or because students perceive less effort and therefore judge their learning as higher in the “Reduce” and “Silence” approaches.

Accepting High Perceived Effort

One important route to improve effort regulation in desirable difficulties is by getting students to understand the positive relation between effort and learning in this context, and to have them reject their erroneous beliefs about high effort as indicative of poor learning and about desirable difficulties as not being conducive to

Table 1 Approaches to improve monitoring and regulation of effort during desirable difficulties

	ACCEPT effort	REDUCE or SILENCE effort
Strategy level	Educate about effectiveness of learning strategies and paradoxical effect of desirable difficulties on perceived effort and perceived learning	
Task level	Increase perceived learning: Have students experience the benefits of desirably difficult learning strategies	Have students experience desirable difficulties recurrently to experience the decrease in effort and increase in learning
	Increase reward	Adapt (perceived) task length, (perceived) time left
Learner level	Motivation regulation strategies (Zepeda et al., 2020) to find value, reduce costs, reframe appraisals and attributions, and create challenges	Motivation regulation strategies (Zepeda et al., 2020) to find value, reduce costs, reframe appraisals and attributions, and create challenges
		Self-adapt (perceived) task length, (perceived) time left
		Increase importance (e.g., by increasing time pressure or increasing goal)

learning. In this situation, learners may judge effort to be high, but they should be willing to *accept* it and overcome their erroneous belief that high effort is not valuable to learning (see Fig. 3a for how the relations are predicted to look after intervention). The general goal of these interventions is to increase learners' awareness of the importance of desirable difficulties for long-term learning and transfer, or put differently, to come to appreciate that effort has added value. Not only effort experiences and their biases need to be tackled, but also experiences of learning need to be simultaneously considered. To do so, debunking of misbeliefs about effort and learning is needed, and this will cost time and potentially lead to some resistance in students who hold strong idiosyncratic beliefs (Biwer et al., 2020b). Note that a combination of interventions at the task, strategy, and preferably also learner level is needed to induce sustainable change. Ultimately, they may still perceive effort to be high, but they will change their data-driven, negative interpretation of effort to a goal-driven, positive one where high effort is an indicator that learning is happening.

Recent research on changing erroneous effort beliefs, where learners' beliefs were framed or primed that high effort is important for learning, has shown some positive effects in increasing effort investments and improving learning outcomes (Muenks et al., 2016; Oyserman et al., 2018). However, these effects were generally short-lived, and it is unknown whether they transfer to other contexts. Moreover, these studies failed to incorporate the intricate relation between perceived effort and perceived learning, and generally attempted to change learners' overall effort beliefs, not acknowledging that these are dynamic, task-based experiences that develop contextually and continuously in relation to learning experiences. The framing and priming studies also did not incorporate desirably difficult learning strategies, which are paramount when aiming to improve long-term learning. That is, if effort beliefs are changed and learners' effort investments increase, this does not necessarily improve learning outcomes as students might be doing more of the same ineffective strategies. Only when the extra effort is invested in desirably difficult, effective learning strategies will long-term learning outcomes improve.

Examples of successful interventions at the strategy level cover several types of learning strategy training programs provided in small groups (Biwer et al., 2020a; Biwer et al., 2020b), or online (Bellhäuser et al., 2016; Broadbent et al., 2020; Endres et al., 2021). These programs educate learners about the effect of learning strategies, and (in)directly address the paradoxical relation between perceived effort, perceived learning, and actual learning in desirable difficulties. Reber and Greifeneder's (2017) call to teach learners about the biases regarding the disfluency of learning should also be mentioned here. These training programs depend on teachers or mentors, who endorse the importance of and understand how to teach the use of desirable difficulties. Research shows that, just as students, teachers suffer from misbeliefs and lack adequate knowledge about effective learning strategy use (Morehead et al., 2016; Surma et al., 2018). Providing adequate teacher training therefore should precede student training. For more information on frameworks that describe the necessary conditions for such a training program, the Study Smart framework (Biwer & de Bruin, 2023) and the Knowledge, Belief, Commitment, and Planning (KBCP) framework (McDaniel & Einstein, 2020; McDaniel et al., 2021) provide important starting points. Note that the KBCP framework does not emphasize the

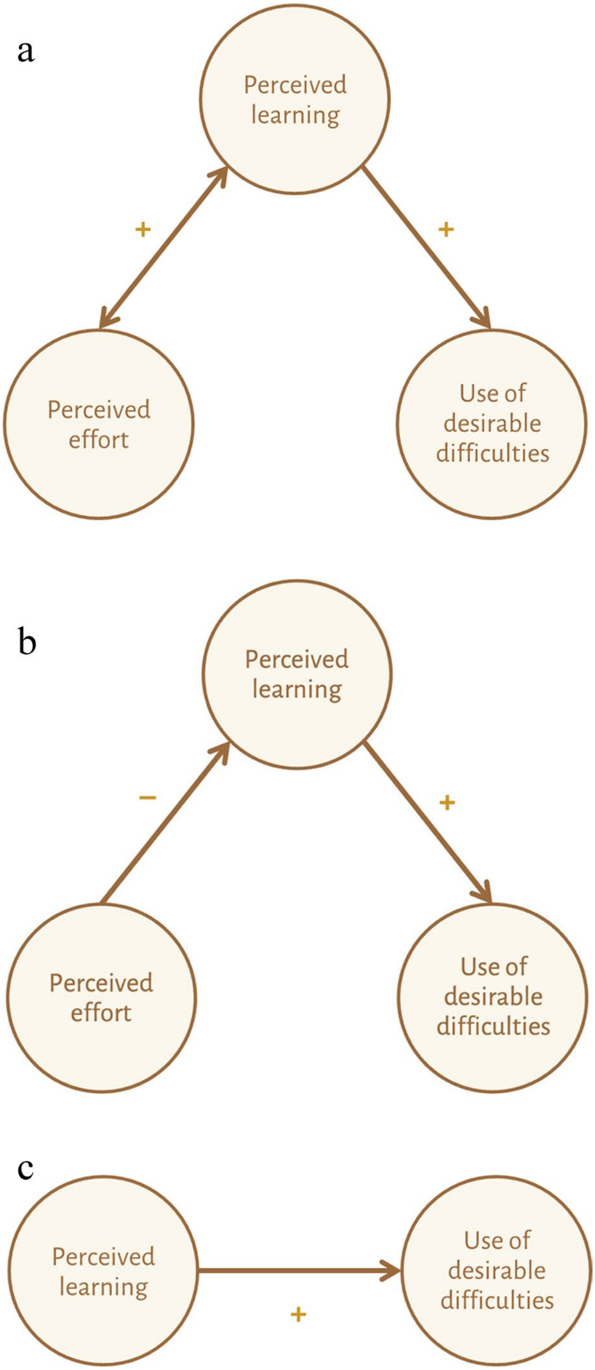


Fig. 3 **A** Accept effort: The predicted relations between perceived effort, perceived learning, and learners' engagement in desirable difficulties after intervention when learners accept that desirable difficulties cost effort. **b** Reduce effort: The predicted relations between perceived effort, perceived learning, and learners' engagement in desirable difficulties when perceived effort is reduced after intervention. **c** Silenced effort: The predicted relations between perceived effort, perceived learning, and learners' engagement in desirable difficulties when perceived effort is silenced because of high importance or flow

importance of improving learners' perceived effort as the Study Smart framework does.

At the task level, interventions can be designed that have students *experience* and reinterpret the high effort that comes along with desirable difficulties by having learners reflect on those experiences, while making the positive effect on actual learning more salient. Providing learners with feedback on their actual learning results is necessary to educate learners about the biases in their perceived effort and learning, as the feedback will often show that the desirably difficult learning strategy did pay off. In turn, perceived learning will increase, and this will also affect effort interpretations.

Hui and colleagues (2021) examined the effect of performance feedback when learners studied human anatomy pictures and their names and had to choose either restudy or retrieval practice after an initial study round. Those students who experienced the benefits of retrieval practice more often chose this strategy after performance feedback. Individual feedback led to more long-term choices for retrieval practice compared with a general instruction that explained the benefits of retrieval practice. Hui et al., (2021a, 2021b) did not report changes in effort across learning trials, which indicates that learners accepted the higher effort and adopted a more goal-driven approach. This is actually a form of conditioning; by pairing high effort with feedback about high learning outcomes multiple times, learners form a new association and come to interpret high effort in a positive manner.

Note that the feedback should take into account the potential delayed learning effect such as in the case of retrieval practice. This can be done by providing feedback at several time points, thus revealing the discrepancy between immediate and delayed learning results. In sum, we propose that, to increase engagement in desirable difficulties, the subjectively perceived effort, the perceived learning effects, and the actual learning effects simultaneously need to be addressed. Learners need to become aware of the positive relation between effort and actual learning effects, and of their biases in perceived effort and perceived learning. Only when all three factors are addressed will learners sustainably change their perceptions of the effect of desirable difficulties, and will they invest prolonged effort into them.

Another intervention at the task level is to add or increase a reward for high effort in desirable difficulties. Making the positive effect on learning salient could act as a reward, but examining the effect of rewarding effort is also worth exploring. Rewarding effort could, for example, be done by increasing the incentive for use of desirable difficulties and by analyzing how the reward affects use of desirable difficulties over time. Recent research (Clay et al., 2022) showed that rewarding high effort on a working memory task (the N-back task) led to higher choices for more difficult tasks during a transfer task (a math task) where the reward was absent. In educational settings, this is of course only possible within controlled learning settings and the effects of such interventions on use of desirable difficulties and transfer to novel contexts remains to be examined. Finally, recent research revealed that framing the feeling of discomfort while engaging in a task as a sign of improvement in knowledge or skill motivated engagement in the task and improved goal achievement (Woolley & Fishbach, 2022). Whether and how this applies to the context of desirable difficulties is an important question for further research.

The above underlines that the effort experiences are highly contextualized: The paradoxical relation between perceived effort and learning can most convincingly be shown while working on real learning tasks. Accordingly, interventions to change effort experiences and improve effort regulation need to be contextualized. Such contextualized, experiential interventions need to be complemented with explanatory and reflective activities, for instance through training programs described at the strategy level. Explanation of what desirable difficulties actually are and what learning strategies are preferable under which circumstances is necessary (Biwer et al., 2020a; Biwer et al., 2020b). Reflection is beneficial to ensure learners' awareness of these explanations and to set goals related to incorporation of these strategies into their self-regulated learning. The goals of such interventions are (1) to override erroneous perceptions of effort and learning, (2) to improve learners' understanding and internalization of the efficacy of desirably difficult learning strategies, and (3) to increase learners' use of these strategies. The effect of such interventions depends on how they tackle the perceived effort-perceived learning-use of desirable difficulties triangle. Note that these interventions can also change use of desirable difficulties when learners perceive a negative relation between learning and use of desirable difficulties (Relation 3 above). Educating them about this erroneous belief and explaining that desirable difficulties are worth the effort is likely to increase their willingness to engage in desirable difficulties.

At the learner level, learners can be stimulated to engage in motivation regulation strategies that make them appreciate high effort and become more goal-directed. These should be combined with strategy level interventions, and where possible with task-level interventions, to ensure willingness to become more goal-directed users of desirable difficulties. Motivation regulation strategies such as self-talk and picturing your future self (Zepeda et al., 2020) seem particularly promising in this regard as they specifically aim at having learners persist when things get rough. Zepeda and colleagues (2020) review five motivation regulation strategies and provide evidence for interventions based on these strategies that improved course performance. For a complete overview and detailed description, we refer to their paper. Finally, learners can be stimulated to create and seek learning conditions that provide an optimal balance between their skill level and the level of challenge of the task at hand, as this will optimize chances of experiencing "flow" (Nakamura & Csikszentmihalyi, 2014). In a state of flow, effort is typically intense, and concentration is high, but learners' goal-directedness has them continue and accept the high effort to "make it happen" (Swann et al., 2016).

Reducing and Silencing Perceived Effort

A second route of improving effort regulation towards desirable difficulties is by reducing or even entirely silencing perceived effort and thereby, likely, increasing perceived learning. The goal of these interventions is to increase learners' experience of fluency during learning. In this route, the data-driven effort interpretation remains, but learners' willingness to put in effort increases because less effort is perceived to be needed (see Fig. 3b for the reduced effort relations after intervention, and Fig. 3c for the silenced effort relations after intervention). These interventions all categorize under the task and learner level, because at the strategy level, effort can be reduced only to a limited extent. As mentioned, desirable difficulties tend to increase germane load, but this load is conducive to learning and reducing it will compromise learning effects.

One approach at the task level to increase feelings of fluency during desirable difficulties is having learners engage in the strategy recurrently across time. That is, learners will likely perceive less invested effort as they engage in a desirably difficult learning strategy more frequently. Via this experience, their feeling of fluency during learning is increased. These experiences can be supplemented with feedback that makes them explicitly aware of the decrease in effort and increase in learning at the task level when engaging in desirable difficulties (Hui et al., 2021a, 2021b). Reducing effort and increasing feelings of fluency at the task level and learner level is further achieved by manipulating (perceived) task length and (perceived) time left. First, manipulating (perceived) task length can be achieved by segmenting the task into smaller chunks (Castro-Alonso et al., 2021). This is known to reduce perceived difficulty, and therefore will also affect perceived effort and increase the feeling of fluency.

Similarly, at the learner level, learners can decide to segment their study sessions, study tasks, or learning goals into smaller pieces. At the study session level, this is for example referred to as the "Pomodoro technique," first described by Francesco Cirillo (2006, 2018) who divided study sessions into uninterrupted sections of 25 min. The shorter time interval is thought to make it easier to maintain focus and inhibit distractions. Scientific evidence for this approach, however, is lacking and it remains to be examined whether this approach actually reduces effort and improves learning. In general, research on optimal break-taking or pausing during learning is highly limited and calls for attention. Another potential way to reduce effort on desirable difficulties is to engage in what elite athletes term "teleoanticipation" (Edwards et al., 2011). By mentally planning their race or training session in the smallest details, they are also able to plan their effort investment and this self-regulation increases a sense of control and reduces perceived effort. This is still uncommon and underexamined in educational psychology, but bears potential as it can aid in distributing effort effectively.

At the learner level, the motivational regulation strategies mentioned above can also be implemented to reduce the experienced effort (Zepeda et al., 2020). Moreover, learners can reduce the experienced effort in desirable difficulties by studying together with peers. When peer groups function well, collaborative learning is known to increase enjoyment and helps overcome struggles, both of which contribute to lowering perceived effort. Alternatively, learners can study with digital peers, by opening a YouTube "Study with me" video and using that to decrease effort needed to stay on task, and pause regularly, but also to have the sense that they are not studying alone. All these interventions will potentially contribute to higher perceived fluency and lower perceived effort. Finally, reducing (perceived) effort at the learner level can be achieved by offloading the organizational aspects of using desirable difficulties to technology, that is, by using an app such as the flashcard app Ankiweb (Bailey & Davey, 2011). The apps take control over when to rehearse which study materials based on a memory-enhancing algorithm, lowering the learner's load of self-management. Some of these apps also provide direct feedback on performance, thus contributing to increasing the salience of actual learning results.

Finally, perceived effort can be reduced by manipulating the (perceived) time available to complete a task. This reduction can be achieved among others by deceiving learners about the end point of a task, giving them the false sense that the task is shorter than expected. Research in sport sciences has revealed that athletes are more willing to invest effort when the (perceived) end point is in sight (Jones et al., 2013). It is possible this effect also applies to cognitive learning tasks. That is, if the completion of the task is in sight, it will lead to the perception that effort is manageable. Another way of deceiving about the endpoint of a task may be conducive to effort regulation is by interrupting completion of the task close to completion. This phenomenon is also termed the "Hemingway effect" after the author Hemingway, who advocated that to write prolifically you should always stop when you are going well (Oyama et al., 2018). Recent research shows that this interruption increased motivation to complete the task because of increased self-efficacy in completing it successfully (Oyama et al., 2018). Reducing the time available to learners is also known to make learners take a more goal-driven approach to learning and disrupt the negative correlation between perceived effort and perceived learning (Baars et al., 2020).

A final, but less common situation arises when learners attribute high importance to a task, for instance because there is a pressing deadline and/or because it is of great personal or professional importance. In this situation, perceived effort is not simply reduced, but silenced entirely or neutralized for a certain time period (see Fig. 3c). In terms of expectancy-value theory (Barron & Hulleman, 2015), the high costs of *not* engaging in the learning activity are what motivates the effort silencing. That is, even though actual invested effort is high, the negative interpretation of high perceived effort plays a minimal role in task engagement, because the highly goal-directed behavior leads to a state of what in movement sciences is termed "compensation" (Bompa, 1996). Compensation in the learning context can be defined as optimizing attentional focus as well as its duration while ignoring effort perceptions. Because the learner decouples the association between perceived effort, invested effort, and perceived learning, they can focus entirely on maximizing learning. This situation occurs for example, when students cram all night to prepare for an exam or to finish an essay. Because of the high importance, a state of compensation is possible that enables students to continue where they would normally have long stopped to rest, or to have them take shorter breaks than usual. Breaks are taken to recover from fatigue or to regain energy through eating, drinking, and moving, not because the balance between perceived effort and perceived learning is off.

Critically, this state of compensation can only be maintained for shorter time periods, however, because eventually rest is needed and because the compensatory state puts the learner at risk of exhaustion if prolonged extensively or repeatedly frequently. While it is debatable whether the state of compensation as it is typically used is recommendable to learners, it is prevalent among higher education students with about 60% of the students admitting they have "pulled an all-nighter" before (Thacher, 2008). At the same time, little research exists as to the circumstances that make compensation potentially effective, and how to promote use of desirable difficult learning strategies while doing so. Only when effective learning strategies such as distributed practice are applied will such a state of compensation pay off in the long term.

Improved Effort Monitoring, but not Improved Effort Regulation

There are circumstances when perceived effort is accepted, reduced, or silenced, but learners still refrain from increasing effort regulation towards desirable difficulties. This situation occurs when learners lack sufficient knowledge, skills, or time to engage in desirable difficulties effectively. For example, when learners are only made aware of the paradoxical relation between perceived effort and learning, or when learners are only told about what desirably difficult learning strategies are without support and feedback on how to use the strategies they will be unable to use desirable difficulties effectively (Biwer et al., 2020a). Learners will experience frustration, because they are motivated to change their learning behavior yet struggle to put the learned lessons in practice. We therefore plea for learning strategy programs to always include practice and feedback with the learning strategies, and to maximize embedding of the program into regular learning and teaching contexts to optimize transfer. Even when they do have the necessary knowledge and skills, circumstances can occur when learners still do not invest effort. Such circumstances can be linked to a state of paralyzing or choking under pressure, where learners experience the burden of work as too high and fail to get started or quit prematurely knowing they cannot manage the task load (Mesagno & Beckmann, 2017). Choking under pressure can of course happen even when learners have sufficient experience with the effective learning strategies.

Discussion

In our Start and Stick to Desirable Difficulties (S2D2) framework, we describe how perceived effort and perceived learning play a central role in deciding to (dis) engange in desirable difficulties. We also describe how these insights have been and should continue to be translated to research that aims to increase sustainable engagement in desirable difficulties during self-regulated learning. Specifically, a shift is needed in research towards examining how at the strategy instruction level, the task design level, and the learner level learners can be supported to (1) gain accurate knowledge of desirably difficult learning strategies, (2) practice effectively with these strategies, and thereby (3) accept, reduce, or silence the high perceived effort that (initially) accompanies desirable difficulties. Moreover, we argue that tackling erroneous interpretations of effort during desirable difficulties should be done simultaneously with tackling perceived learning and considering actual learning effects. Only when all three factors are considered can learners understand the paradoxical relation, refute erroneous beliefs, and gain confidence that desirable difficulties are worth the effort.

Creating understanding of desirable difficulties and designing conditions that help accept or reduce perceived effort is equally important as teaching learners under what conditions learning strategies are (not) effective for long-term learning. Only when both of these aspects are addressed will sustainable use of desirably difficult learning strategies be fostered. Note that our approach does not explain how teachers can directly incorporate desirable difficulties in their teaching to students, as our aim was to explain students' *self-regulated use* of desirable difficulties in the self-study context. However, we strongly encourage teachers to (continue to) use desirable difficulties in their teaching, as their students will likely benefit greatly. We also encourage researchers to examine how teachers' use of desirable difficulties can transfer to students' self-regulated use of these strategies. Modeling of effective self-regulated learning by teachers is known to stimulate students' self-regulated learning skills (Dignath & Veenman, 2021), and this may apply to self-regulation towards desirable difficulties just as well.

To complicate matters further, experiences of effort and learning are often shaped at both the task-level and strategy-level, either separately or simultaneously. So, to what extent a learner judges learning circumstances to be taxing depends both on how difficult the learning material is perceived to be, and by the load associated with the learning strategy. It is likely that learners are often unaware of these separate influences and confuse them. The source of the experienced effort and learning is important to identify as it determines how to intervene to change learners' erroneous perceptions. Research is needed to understand how perceived effort and perceived learning during desirable difficulties come about at both the task level and strategy level, how perceived effort and learning are related, and, finally, how biases in this relation can be overcome.

We further argue that future research should incorporate interventions that measure perceived effort, perceived learning, and actual learning (preferably in combination with explanations of effective learning strategies) on multiple occasions across time, and that examine how to provide (individualized) feedback to learners on how these factors change across time. Even when learners' interpretations are based on only one of the factors, mending those misinterpretations is best done including all three factors. For example, when perceived effort is extremely high and perceived learning no longer plays a role, learners are helped by understanding that the high effort is worthwhile because of a delayed learning gain. Given the often delayed effects of desirable difficulties, multiple measurements across time are essential to convince learners of the learning effects and reveal that the initial high perceived effort and low perceived learning become tolerable and profitable with repeated exposure. This acceptance of effort can occur within the span of days or even across learning trials in a single study session (Onan et al., 2022). Little is known about how learners perceive the effort and learning of desirably difficult strategies when they engage in them over the course of weeks or months, as most research until now has implemented single or dual session designs.

Previous research has revealed a potential drawback of performance feedback; in any learning context, there is always a subset of learners who will not benefit from the suggested desirable difficulty but learn more under control conditions (e.g., by restudying instead of retrieval practice, Hui et al., 2021a, 2021b). For these learners, the difficulty of the learning material is probably too high; the desirably difficult strategy itself not benefiting them is less likely (Guadagnoli & Lee, 2004). Individualized feedback should then be avoided as it will lead to decreased use or even resistance against the desirable difficulty, or the learning task should be simplified so these learners will also benefit from desirable difficulties. General feedback and recognizing when the task difficulty is appropriate to benefit from desirable difficulties are further potential interventions to help learners in these circumstances.

Examining time effects also applies to the question of overriding habitual ineffective strategy use. Learners who self-regulate their self-study behavior usually have already developed habitual learning strategies, albeit often ineffective, which are characterized by easy accessibility, easy application, and high confidence in their utility. Incorporating desirable difficulties into self-regulated learning is therefore also a matter of becoming aware of ineffective habits and the triggers to using these habits, overriding existing strategy use, and creating new, more effective habitual strategy use. We agree with Fiorella (2020) that findings from the behavior change literature are of relevance here, as these studies provide insights into how habits are overridden and created. This research should examine whether and how interventions differ when tackling the preparation versus the execution phase of a habit. Merging behavioral change paradigms with educational psychology paradigms is needed to bring this research forward and evidence exists that a behavioral-change-based narrative approach can increase awareness of desirable difficulties (Hui et al., 2021a, 2021b). We also see value in connecting to movement sciences research where insights into how athletes silence effort during exercise and enter a state of "compensation" may prove transferable to learning research. When under high time pressure, students are known to exemplify similar undesirable and ineffective behavior (Thacher, 2008). However, if learners can use this behavior adaptively and in limited amounts, while combining it with the use of effective learning strategies, it may lead to a novel route of self-regulated learning behavior that amplifies the range of approaches to optimize self-regulation of effort to start and stick to desirable difficulties.

In line with several views on self-regulation as overriding, a default response of inaction, free roaming thought, or mind wandering (Inzlicht et al., 2021), deciding to start and stick to a learning task is goal-driven, self-regulatory behavior. These goals can give way to on-task processing experiences, including effort. However, research on effort experiences (Baars et al., 2020) often describes these as data-driven, being determined mostly by on task experiences of difficulty and learning. In reality, learning goals and the ensuing experiences of effort are not unilateral or polarized, but they dynamically interact when preset goals, task experiences, and contextual factors (e.g., fatigue, distractors) meet. In our view, effort experiences are a result from interactions between top-down processes, including learning goals on one hand, and on-task processing experiences and contextual factors on the other hand. To improve learners' investments in desirable difficulties, the aim is to find an optimal balance between increasing learners' goal-driven approach and adapting the learning environment or the learning task to decrease perceived effort and increase commitment to desirable difficulties. So, instead of pitting data-driven and goal-driven effort interpretations against each other, we argue that effective learning strategy use is a matter of both making top-down goals more prominent by explaining the importance of desirable difficulties for learning and managing bottom-up task experiences and task contexts by having learners reflect on decreases in effort during desirable difficulties.

Our view emphasizes the need for adequate learning strategy training, including ample exercises to practice the learning strategies under the guidance of a coach, mentor, or knowledgeable teacher. This will also increase learners' confidence in their strategy use. Any attempts to improve learners' effort interpretations or use of motivational regulation strategies will be in vain if learners lack sufficient experience with and confidence in effective strategy use. From a practical educational perspective, it is paramount for those interacting with students to consider their strategy knowledge and skills when they express motivational problems such as procrastination or lack of interest. What is sometimes seen as "lazy" is often not knowing how to approach a task effectively or manage the high load of the task. In self-regulated learning environments, much is dependent on students' own motivation and consequentially there is a strong focus on improving motivation, but it should be carefully explored whether a lack of learning strategies is the unknown cause of motivational problems. Also, within our view, procrastination may not always be a self-efficacy problem (Klassen et al., 2008), but could be an adaptive way of students to increase importance and reduce perceived effort. By increasing time pressure through procrastination, students might be able to silence their subjective experiences of effort and become more goal-driven, doubting less, acting more quickly, and being more content with the results. Of course, increasing the time pressure through procrastination brings the risk of having too little time to produce an acceptable result and may increase stress. Whether, when, and how procrastination benefits effort regulation is an important question for future research.

A final pressing issue that was not covered in the current writing is how learners can self-monitor whether a task or strategy is desirably difficult or merely too difficult. Whether a learning activity is effective for increasing long-term learning depends on optimizing the desirable difficulty of the learning material and the learning strategy in interaction with the student's prior knowledge and strategy skills. The desirably difficult learning strategies mentioned here such as retrieval practice, distributing practice, and interleaved practice work under many circumstances for many learners, but not always and not for all (Hui et al., 2021a, 2021b, 2022. To tackle this issue, two approaches, possibly consecutively, are proposed. First, a teacher or mentor determines what learning strategies are most likely desirably difficult for their learners within their learning context. This approach is implemented in several learning strategy programs (Biwer et al., 2020a; Cogliano et al., 2020), where the generalizability of the learning strategies across different categories of learning tasks is also discussed and learners gain confidence in the effectiveness of the strategies in their specific context. Learners are made aware of the different functions of the learning strategies, where some are helpful to increase elaboration during initial encoding (e.g., self-explanations), whereas others enhance storage in long-term memory (e.g., retrieval practice). Within such constraints, general recommendations are possible.

Teacher-determined strategies pave the way for the second approach, where learners themselves judge the desirable difficulty of a learning strategy for specific learning material they need to study. Being able to judge the desirability of the difficulty depends on ample experience with the strategies for different learning materials, and feedback on the use and efficacy of the learning strategy through a mentor or through formal assessment. Future research should focus on unraveling how characteristics of the learning strategy and learning material interact with the characteristics of the student to create desirable difficulties, and how learners can develop skills to self-monitor the desirable difficulty of a learning strategy given specific learning material. Note that this research should also unravel whether the timing of the monitoring judgment matters. Recent research shows evidence for two distinct monitoring abilities: one taking place during encoding and one during retrieval (McDonough et al., 2021). It is possible that these two types of monitoring abilities show distinct patterns in their relation to perceived effort and use of desirable difficulties.

Conclusion

With the goal to enhance students' engagement in desirable difficulties during self-regulated learning, we propose here a need for acknowledging and understanding the role of perceived effort and perceived learning when students self-regulate their use of desirable difficulties. Students' perceptions of effort and learning interact dynamically in mostly unknown ways, and tackling these often erroneous perceptions is necessary to enhance students' willingness to start and stick to desirable difficulties. Despite the evidence for their effectiveness for long-term learning, the uptake of desirable difficulties is still too low in students in higher education (Hartwig & Dunlosky, 2012). We hope that the current writing contributes to an expansion of research towards the self-regulated use of desirable difficulties in authentic learning environments, with an emphasis on understanding and improving perceptions of effort and learning in interaction with measures of actual learning.

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Declarations

Conflict of Interest The authors declare no competing interests.

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