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Help me understand: Adaptive information-seeking predicts academic achievement in school-aged children

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ABSTRACT

Information-seeking after making mistakes or when experiencing uncertainty, including bids for help, is an important aspect of self-regulated learning. We compared information-seeking during a puzzle-solving task in 8- and 9-year-olds, 11- and 12-year-olds, and 16- and 17-year-olds (N = 197). We found that 8- and 9-year-olds were less efficient in their information-seeking, in that they were more likely than other age groups to seek help following a correct response. Additionally, the rate of information-seeking following an error was positively related to academic achievement, measured as Grade Point Average (GPA), above and beyond general task performance. This result was replicated in a larger and more diverse sample of 13- to 20-year-olds (N = 2,922). Overall, this research shows that information-seeking improves throughout childhood and this behaviour predicts academic success, highlighting the practical importance of this self-regulated behavior.

1. Introduction

To learn and improve, students need to determine when to seek out more information. Information-seeking may be critical to fill gaps in understanding but can also be costly if students perseverate seeking information that is irrelevant or unavailable. Therefore, students benefit from efficient information-seeking, that is focusing on situations that generate uncertainty or when they have made a mistake. This efficient information-seeking is a type of self-regulated learning (Karabenick & Berger, 2013; Karabenick & Dembo, 2011) and may play an important role in successful academic achievement (Ryan & Shin, 2011). Despite its importance, we know relatively little about students' ability to seek information as a way to learn from their mistakes and how this ability develops across childhood and adolescence (Karabenick & Gonida, 2018). The goal of the present study is to examine developmental differences in children and adolescents' information-seeking ability during problem solving and its potential association with academic achievement.

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1.1. Adaptive information-seeking

Adaptive information-seeking requires adopting strategies that maximize learning and/or performance (Karabenick & Berger, 2013). These strategies include the ability to translate an awareness that one's current knowledge is not sufficient into actions that will fill these gaps in knowledge and understanding. These actions may include deciding to seek information, identifying the most helpful source of information, and updating knowledge (Nelson-Le Gall, 1981). Therefore, during information-seeking the type of information sought and the source of information can vary. Indeed, receiving information in the form of a hint or explanation (i.e., instrumental help) is thought to be more beneficial than receiving the correct answer (i.e., executive help) because hints or explanations can improve learning through scaffolding and by promoting problem-solving (Nelson-Le Gall, 1981; 1985). Students can also seek information from non-social or social sources (e.g., an internet search versus teacher), termed information vs. help-seeking respectively (Zimmerman & Martinez-Pons, 1986). The decision of whether or not to seek information may vary by social and non-social sources. For example, students may more readily ask for information in an online learning environment because they do not fear social embarrassment for their lack of knowledge (Aleven, Stahl, Schworm, Fischer, & Wallace, 2003). However, researchers have also recognized similarities across these sources of information. For example, both social and non-social sources can vary in how well they adapt or specialize to individual learners' needs (Puustinen & Rouet, 2009).

In the current research, we assess students' decision to seek helpful tips during an online problem-solving task. We elected to focus on tips because they were expected to be particularly beneficial for learning (Nelson-Le Gall, 1981; 1985). We used an online computer task to examine how students seek information in the absence of social interactions, a skill that is becoming increasingly more common at younger ages with the prevalence of remote and online learning (Morgan, 2015; Searson, Jones, & Wold, 2011). We investigate the development of students' ability to seek information when it would be the most beneficial (i.e., following errors) and how this decision relates to their immediate and broader long-term learning. We examined immediate learning through a final test phase in the current task, during which participants responded independently and could apply strategies learned through a previous help-seeking phase. In addition to promoting learning in the current task, information-seeking behaviors in the present task may reflect broader learning strategies (e.g., propensity to ask for help more frequently) and thus be related to long-term learning including academic achievement. We took an individual-difference approach to probe the relation between information-seeking and retrospective and prospective academic achievement. We first established this relation in a sample of elementary through high-school students and then we replicated the results in a larger and more diverse sample of high-school students.

1.2. Learning from errors and information-seeking

One context to examine adaptive information-seeking strategies involves assessing whether children seek information in responses to their errors. Errors expose knowledge gaps, thus providing opportunities to reassess learning processes (Butler & Winne, 1995; Tulis, Steuer, & Dresel, 2016). For example, children and adults are more cautious (Dutilh et al., 2011) and respond more slowly to trials following errors (Gupta, Kar, & Srinivasan, 2009; Wiersema, van der Meere, & Roeyers, 2007) and this reassessment could be used to potentially avoid additional mistakes. Critically, seeking information following errors, as opposed to correct responses, is considered particularly adaptive because it provides a means to correct misconceptions and improve learning (Metcalfe, 2016). Information-seeking following correct responses may also benefit learning by solidifying or elaborating on existing knowledge (Butler, Karpicke, & Roediger, 2008; Roediger & Karpicke, 2006), but is expected to lead to smaller learning benefits given that there is less knowledge to be gained. Although research shows that children notice their errors (e.g., Gupta et al., 2009; Wiersema et al., 2007), it is not clear whether children are motivated to seek additional information after being informed that they made a mistake.

Information-seeking as a strategy to learn additional helpful or corrective information following a mistake, which we will refer to as post-error information-seeking, is an aspect of learning that has been largely ignored in the information-seeking literature (but see Huet et al., 2016 with adults). That is, studies that objectively assess information-seeking behavior typically focus on understanding how children independently recognize gaps in their knowledge, in the absence of feedback, and seek to overcome them by asking for help on the current problem (Puustinen, 1998; Roll, Aleven, McLaren, & Koedinger, 2011). Typically, these task-based studies assess information-seeking in a social context where children seek help from an experimenter *while* they are solving a problem and *prior* to attempting a response (Butler & Neuman, 1995; Coughlin, Hembacher, Lyons, & Ghetti, 2014; Puustinen, 1998). Under such conditions, children must assess their own knowledge to determine when help would be most beneficial to maximize their current performance. However, this approach cannot clearly establish the cognitive strategies children use to motivate their behaviors and whether children ask for help to maximize performance (i.e., increase knowledge and avoid mistakes) on the current problem and/or whether they seek help to support their general learning. Inferences from these types of tasks are further complicated by the fact that this research does not typically include follow-up assessments to examine whether help-seeking improves later performance (but see Newman, 1998). Furthermore, in social contexts other factors, such as fear of embarrassment (Newman & Goldin, 1990), may also impact children's frequency of help-seeking.

To better capture students' motivation to increase their learning, in the current study we focused on students' choice to seek helpful information in the form of a tip *after* they provided a response and received feedback about the accuracy of their response in an online task. By asking for tips from an online source, we may minimize the influence of social factors in information-seeking. Critically, by examining information-seeking following a response, we can examine errors and correct responses focusing on a cognitive account of information-seeking strategies. When students seek information after generating a response, under an optimal cognitive learning strategy they should be more likely to seek information following an error than a correct response given that errors are particularly beneficial for learning (Metcalfe, 2016). Furthermore, their current mistake cannot be corrected and therefore information-seeking is

more likely to reflect a motivation to improve long-term knowledge and avoid future mistakes. In contrast, if students seek information based on the development of other factors, such as a desire for autonomy or fear of embarrassment, these would likely be reflected in information-seeking overall regardless of response accuracy (i.e., decreased information-seeking for both correct and incorrect responses).

Focusing on cognitive strategies, previous research demonstrates that explicitly generating a candidate answer can lead to learning benefits (Potts & Shanks, 2014), particularly following errors (Metcalfe, 2016; Metcalfe & Xu, 2018). Furthermore, providing additional explanatory or scaffolding information following errors leads to better learning than only receiving corrective feedback (Finn & Metcalfe, 2010), suggesting that helpful strategies on how to solve a problem may be particularly beneficial for long-term learning as opposed to simply providing a correct answer. Although some research has investigated children's help-seeking behavior after an initial independent answer in the absence of help (Nelson-Le Gall, 1987; Nelson-Le Gall, Kratzer, Jones, & DeCooke, 1990; Newman, 1998), in these studies children did not receive feedback about the accuracy of their answer and had the opportunity to change their answer to the current problem after receiving help. Therefore, as in the previously discussed line of research, children were highly motivated to seek help as a way maximize current performance and again it is unclear if they were seeking information to also improve later performance on the same task. Importantly, seeking additional information following mistakes that cannot be corrected should improve later performance on the same task when help or feedback is not available, but previous work does not typically examine final independent performance after a help-seeking phase.

1.3. Development of information-seeking

Examining developmental differences in information-seeking is relevant for understanding how self-regulated strategies play a role in students' learning and how these processes may differ across childhood and adolescence. Critically, the capacity to assess one's own knowledge (i.e., metacognition) (Nelson, 1990) has been implicated as an important factor for deciding when to seek help and what type of help would be the most beneficial (Nelson-Le Gall et al., 1990; Tobias & Everson, 2009). Metacognition develops throughout childhood and into adolescence, with older children becoming better at recognizing when they may be incorrect or less knowledgeable (Fandakova et al., 2017). Thus, developmental improvements in metacognition suggest that students' ability to adaptively seek out information may be expected to improve with age. Consistent with this idea, the capacity to seek out information begins in infancy (Goupil, Romand-Monnier, & Kouider, 2016) but develops substantially throughout childhood (Coughlin et al., 2014; Paris & Newman, 1990). For example, preschoolers will turn to an adult for help when they make a mistake or have low confidence about their answer (Coughlin et al., 2014), but older school-aged children are more likely to seek help when they are less certain in their answer (Nelson-Le Gall et al., 1990) and less knowledgeable (Nelson-Le Gall, 1985; Nelson-Le Gall & Glor-Scheib, 1985). Additionally, older compared to younger school-aged children are more likely to ask for information that enhances their learning, such as partial hints and explanations, as opposed to information that is less helpful for learning, such as seeking the correct answer (Nelson-Le Gall, 1987; Puustinen, 1998). Overall, this research suggests that by middle childhood children are able to recognize when they need help and seek the kind of help that is most beneficial for their learning. However, metacognition continues to develop into adolescence (Fandakova et al., 2017), suggesting that developmental improvements in information-seeking behaviors may be observed beyond middle childhood with potential implications for learning into adulthood. Previous research has not compared information-seeking behaviors across a wide age range, making it difficult to examine whether developmental improvements extend into adolescence. Furthermore, this research focused on information-seeking prior to committing to a response or receiving feedback. Therefore, it is unclear if older children's increased metacognitive abilities would extend to information-seeking strategies in contexts where additional information could only be used to improve later performance, with no opportunity to correct current mistakes.

In previous research examining help-seeking, specific age groups were typically assessed (Newman, 1998; Ryan & Shin, 2011; Ryan, Patrick, & Shim, 2005), such as early and middle childhood (Newman, 1990; Newman & Schwager, 1993), or middle childhood and adolescence (Ryan & Shim, 2012; Schenke, Lam, Conley, & Karabenick, 2015), with very few studies assessing across early childhood to adolescence (Gonida, Karabenick, Makara, & Hatzikyriakou, 2014). Importantly, these investigations were conducted with tasks that could not be directly compared across ages. For example, whereas research with younger children typically assessed information-seeking behaviors during cognitive tasks, the majority of research in older children and adolescents assessed information-seeking using self- or other reports (Gonida et al., 2014; Newman & Goldin, 1990; Ryan & Shin, 2011; Ryan et al., 2005; Schenke et al., 2015). Critically, research in adults suggests that actual help-seeking behavior and perceptions of help-seeking are not strongly associated (Huet, Escribe, Dupeyrat, & Sakdavong, 2011; Huet, Moták, & Sakdavong, 2016), suggesting that developmental differences may not be appropriately captured when using different methodologies. Additionally, research with younger children typically used educational tasks where children sought information from a social source, and therefore other factors unrelated to cognitive strategies may have influenced help-seeking (e.g., fear of embarrassment (Butler & Neuman, 1995; Newman & Goldin, 1990)). Overall then, we have a limited grasp of age-related differences in information-seeking using the same task and the specific aspects of information-seeking behavior that improve with development.

1.4. Information-seeking and academic achievement

Children and adolescents who report engaging in adaptive cognitive strategies, including monitoring, planning, and implementing effective learning strategies, show greater academic achievement across domains (Dent & Koenka, 2016; Zimmerman & Martinez-Pons, 1990). For example, children who report engaging in adaptive help-seeking have been shown to obtain higher scores in math achievement tests (Ryan et al., 2005; Schenke et al., 2015) and academic grades (Ryan & Shim, 2012; Ryan & Shin, 2011). This

suggests that self-regulated behaviors, such as information-seeking, may support learning and academic success broadly (Puustinen and Pulkkinen, 2001; Zimmerman, 2002). However, these studies primarily assessed help-seeking via self or other (e.g., teacher) reports and it is not clear whether these findings would hold for behavioral measures of information-seeking. This is because informants' reports may be biased by existing knowledge of academic achievement and this bias could result in an inaccurate or inflated positive correlation. For example, teachers often know which students have low grades and this may lead them to assume these students struggle with other skills including information-seeking. Additionally, self or informant report measures may lack specificity and individuals may not implement their reported help-seeking intentions due to various internal (e.g., embarrassment) or external (e.g., help is not readily available) factors (Huet, Dupeyrat, & Escribe, 2013). By examining post-error information-seeking in an online environment, we can better understand how observed information-seeking behaviors in the absence of potential social factors may relate to academic achievement. Critically, if information-seeking behavior in the current task is reflective of cognitive strategies that are used when individuals face a learning challenge more broadly (within and beyond this task), this behavior may positively correlate with students' general academic ability. We focus on post-error information-seeking because seeking information after mistakes is considered particularly strategic in increasing learning (Metcalfe, 2016).

It is plausible that the role of information-seeking in academic achievement varies across development due to changes in self-regulated learning strategies. Developmental improvements occur in several self-regulated strategies across childhood and adolescence, including greater ability to recognize one's own level of knowledge (Fandakova et al., 2017; Nelson-Le Gall et al., 1990), identify factors that improve learning (Tullis & Maddox, 2020), and optimize study habits to improve learning (Metcalfe & Finn, 2013). Therefore, it is possible that information-seeking may differentially predict academic achievement as other self-regulated skills also emerge, making it important to examine these behaviors across development. For example, information-seeking is evident early in childhood (e.g., Coughlin et al., 2014; Nelson-Le Gall et al., 1990) and younger children may heavily rely on seeking information to fill gaps in knowledge. However, older children may use additionally developed learning strategies such as studying difficult to learn information for longer periods of time (Metcalfe & Finn, 2013). Therefore, information-seeking may be a stronger predictor of academic achievement in younger compared to older children. Although previous research has examined developmental differences in how various metacognitive processes relate to academic achievement (Dent & Koenka, 2016), to our knowledge, no previous research has tested developmental differences in how behavioral measures of information-seeking, particularly following errors, predict academic achievement; thus, we treat this question as exploratory. Finally, there are considerable individual differences in self-regulation skills that have been associated with both cognitive and environmental factors (e.g., socioeconomic status) (Montroy, Bowles, Skibbe, McClelland, & Morrison, 2016). Therefore, it is important to examine whether information-seeking behaviors replicate in different student populations with varying diversity.

1.5. The current research

The goal of the current research was to examine age-related differences in post-error information-seeking in children and adolescents, and whether this behavior relates to task performance and academic achievement. To address these questions, we assessed post-error information-seeking on a problem-solving task requiring matrix reasoning. On a portion of the trials, participants were provided with feedback on the accuracy of their answer and could elect to view a tip demonstrating how to solve the problem. Age groups were selected to span across middle childhood and adolescence when known improvements occur in children's metacognition (Fandakova et al., 2017), their ability to incorporate helpful information into their decision-making (Betsch, Lang, Lehmann, & Axmann, 2014; Selmeczy & Ghetti, 2019), help-seeking behaviors (Newman & Goldin, 1990; Newman & Schwager, 1995), and reported help-seeking intentions (Newman, 1990; Schenke et al., 2015).

We focused on matrix reasoning because it has been used in previous research investigating help-seeking (Puustinen, 1998) and motivation in children (Mueller & Dweck, 1998). Indeed, the task lends itself well to effectively assess post-error information-seeking for multiple reasons. First, matrix reasoning does not depend on prior knowledge of math, science, language or other subjects and has been used across a wide variety of contexts and populations (see Choudhury & Gorman, 1999 for a study with Guatemalan adolescents, and Costenbader & Ngari, 2001 for a study with Kenyan children). This suggests that students would be equally likely to make a mistake based on understanding, effort, and motivation, rather than existing knowledge, and be equally likely to seek more information after making a mistake when motivated to learn new information. Second, to examine if students learn from post-error information-seeking and improve later task performance, we required a task in which information-seeking could not be used to improve current task performance and instead could be used to potentially improve later performance. This was accomplished by using a task in which feedback indicating an incorrect answer did not automatically reveal the correct answer, such as tasks with only two response options, and therefore eliminate the need for further learning. Since there are several response options in matrix reasoning tasks, learning that one is incorrect does not necessarily reveal the correct answer. Furthermore, matrix puzzles are often solved through multi-step or multiple different strategies that can be applied to other problems; thus, making it valuable to gain additional problem-solving skills to aide in solving future tasks.

We tested several predictions. First, we predicted that all age groups would demonstrate higher information-seeking following incorrect relative to correct responses, suggesting adaptive responses to errors. This is consistent with research that shows adaptive information-seeking begins to develop by preschool age (Coughlin et al., 2014). However, we anticipated this difference would increase with age, consistent with the metacognitive improvements observed during child and adolescent development (Fandakova et al., 2017; Ghetti, Mirandola, Angelini, Cornoldi, & Ciaramelli, 2011) and help-seeking literature suggesting older children are more adaptive in their help-seeking (Nelson-Le Gall, 1987; Puustinen, 1998). Second, we predicted greater post-error information-seeking would correlate with higher subsequent performance during a final test phase, when feedback was not provided, consistent with the

idea that errors serve as particularly useful opportunities for further learning (Butler & Winne, 1995). Third, we predicted that greater post-error information-seeking would correlate positively with academic achievement (i.e., school GPA). Since standardized matrix reasoning performance is known to correlate with academic achievement (Rohde & Thompson, 2007), we statistically controlled for matrix puzzle accuracy in order to examine if post-error information-seeking predicted academic achievement above and beyond individual levels of task performance. These hypotheses were tested in 8- and 9-year-olds, 11- and 12-year-olds, and 16- and 17-year--olds in Study 1, and then in 13- to 20-year-olds in Study 2, which was aimed at replicating our findings in a larger and more diverse population of students.

2. Study 1

2.1. Methods

2.1.1. Participants

Participants were recruited from a private K-12 school located in a large Midwestern U.S. city. The current sample includes 194 students: 60 8- and 9-years-old in 3rd grade ($M_{age} = 8.43$, $SD = .50$), 56 11- and 12-year-olds in 6th grade ($M_{age} = 11.36$, $SD = .48$), and 78 16- and 17-year-olds in 11th grade ($M_{age} = 16.47$, $SD = .50$). Sample size was determined by the number of children enrolled in each grade at our school partner. The sample was diverse in terms of race and ethnicity (55.67 % European American/Caucasian, 15.46 % Asian American, 6.7 % Multiracial American, 5.67 % African American, 7.73 % Hispanic/Latino(a) American, 2.06 % International, 1.03 % Middle Eastern, 1.03 % Native American, 4.64 % not provided), sex (47 % female), and academic ability (GPA for 11- and 12-year-olds and 16- and 17-year-olds ranged from 2.67 to 4.28; Fall 2017: $M = 3.75$, $SD = .32$, Fall 2018: $M = 3.78$, $SD = .32$). This study was approved by University of California, Davis institutional review board and qualified for a waiver of consent.

2.2. Materials and procedure

2.2.1. Persistence, Effort, Resilience, and Challenge-Seeking (PERC) Task (Porter et al., 2020)

PERC is a puzzle-solving task consisting of puzzles selected from the Raven's matrices. Puzzles were selected to be of mixed difficulty level, including easy, medium, and hard puzzles. These puzzles were initially selected based on the Raven's testing manual, which provided some information on puzzle difficulty. The puzzles and number of trials were further refined based on previous pilot testing which also demonstrated task performance to correlate with attitudes and beliefs about achievement in expected ways (Porter et al., 2020). Furthermore, the task was designed to be feasible for self-administration in a classroom setting. Although PERC was designed to assess multiple aspects of mastery behaviors, the current study described elements of the task in the context of examining

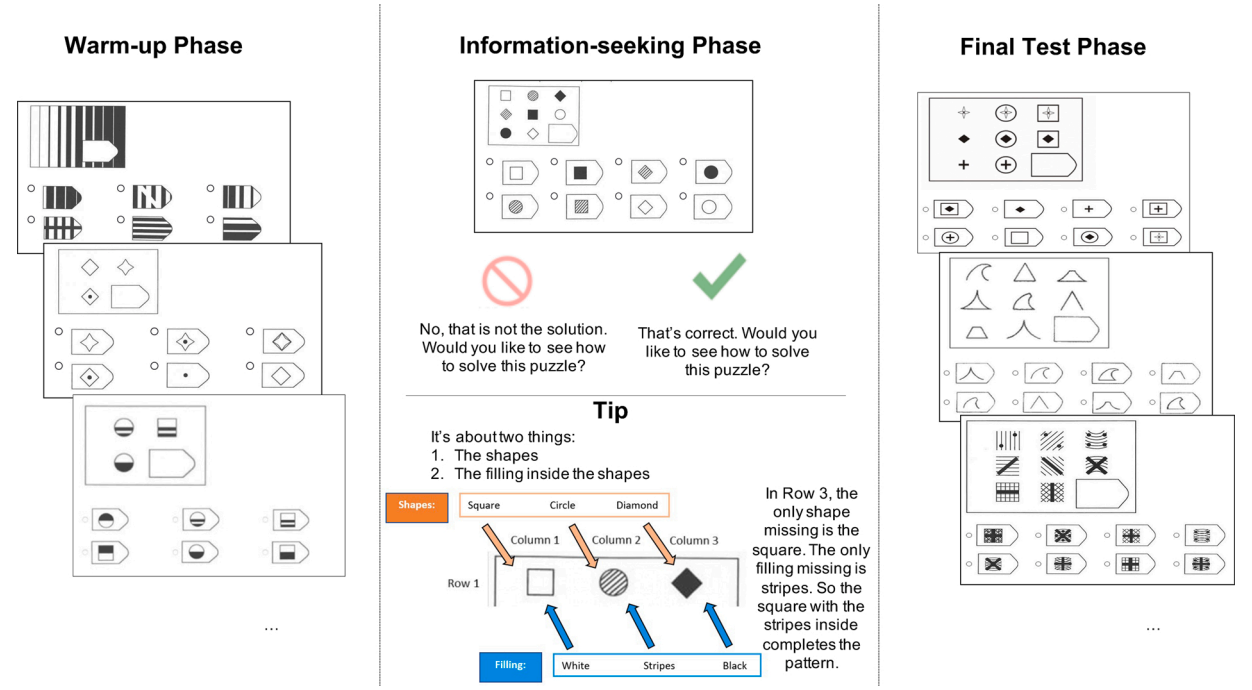

Fig. 1. Task Design. The warm-up phase consisted of a set of 4 easy puzzles. During the information-seeking-phase, participants were presented with 3 medium difficulty puzzles followed by performance feedback and the opportunity to view a tip about how to solve the puzzle. During the final test phase, participants completed a set of 8 or 9 easy and difficult puzzles in the absence of feedback or tips.

novel hypothesis surrounding information-seeking specifically.

The task was administered via computer using online Qualtrics Software during a typical class period in Spring 2018. Instructions were provided on the screen for participants to read. Researchers were not present, and teachers had a minimal role during task administration.

Participants were introduced to the task by being told that strong puzzle-solving is a useful skill that can be helpful for creative or new ways to solve problems and that they can test their puzzle solving skills with the current task. The task had three phases that took approximately 10 min to complete (*Med* = 9.35 min, *SD* = 6.00 min). The warm-up phase included four easy puzzles and familiarized participants with the task. Participants then indicated whether they preferred more or less challenge for the upcoming puzzles. Next, participants completed the information-seeking phase, which included 3 medium difficulty puzzles regardless of the level of challenge participants preferred. After each puzzle, participants received feedback about their response accuracy, since previous literature shows that learning from errors typically occurs in contexts where participants are aware of their mistake (Kornell, Hays, & Bjork, 2009; Metcalfe, 2016). Importantly, participants were also given the option to either move on to the next trial or ask for a tip which described a multi-step strategy on how to solve the puzzle (See Fig. 1). Tips focused on explaining how to integrate relevant information across the presented columns and/or rows in the puzzle. Participants were told this phase will be proceeded by a final phase but were not provided additional details about the final phase in advance. The final test phase consisted of 8 or 9 puzzles including easy and difficult problems; no feedback was available during this phase. However, during this phase, participants could elect to quit after each puzzle or to select "I cannot solve this puzzle". The opt out option was given to reduce stress and frustration for participants who were unable to answer the difficult puzzles and did not want to guess. This also allowed us to potentially examine if participants were opting out of difficult puzzles more often than easy puzzles and whether this changes with age.

There were two versions of this last test phase of the task. Participants were randomly assigned to task versions. Task versions were identical except for the following: in Version 1 the final phase included 8 puzzles with easy puzzles for the last 3 items, whereas in Version 2 the final phase included 9 puzzles with medium difficulty puzzles for the last 4 items. This variability in difficulty allowed us to assess whether post-error information-seeking would be associated with final test performance across both an easier and more difficult final test.

2.3. Measures

2.3.1. Accuracy

Accuracy was measured as the proportion of correct trials completed. Accuracy was calculated for the entire task based on all trials (overall accuracy), trials from the information-seeking phase only, and trials from the test phase only. For analyses involving overall or test phase accuracy, students must have completed at least 2 trials during the final test phase consisting of both an easy and a difficult puzzle. This was done to ensure that task accuracy appropriately captured all levels of difficulty.

2.3.2. Post-error information-seeking

Post-error information-seeking was calculated as the number of tips sought following an incorrect response divided by the total number of incorrect responses during the information-seeking phase.

2.3.3. Post-correct information-seeking

Post-correct information-seeking was calculated as the number of tips sought following a correct response divided by the total number of correct responses during the information-seeking phase.

2.3.4. Academic achievement

Academic achievement was provided from school records for the two older age groups and measured by retrospective (Fall 2017) and prospective (Fall 2018) GPA. GPA measures were cumulative. GPA was taken from school records that used a standard 4.0 GPA scale which converted and averaged class grades on a 100 point scale (i.e., Grades 97–100 = 4.3; Grades 93–96.99 = 4.0; Grades 90–92.99 = 3.7, etc.). The younger age group did not use standard grades to measure academic performance and that is why they did not have GPA information available.

2.4. Statistical analyses

2.4.1. Information-seeking

In order to examine the frequency of information-seeking as function of response accuracy and age group, we used a trial-level logistic multilevel model (MLM) with lme4 in R (Bates, Bolker, & Walker, 2015) based on trials from the information-seeking phase. We predicted whether information was sought (0-no, 1-yes) using fixed effects of 1) accuracy (0-incorrect, 1-correct) in order to examine differences in information-seeking following incorrect relative to correct responses, 2) age group (dummy coded in reference to 8- and 9-year-olds) in order to examine developmental differences, and 3) an accuracy by age group interaction in order to examine whether age moderated the effect of accuracy on information-seeking. Participant was included as a random intercept.

2.4.2. Predicting test performance and academic achievement

In order to examine the relation between final test performance and post-error information-seeking, we conducted a regression analysis predicting test phase accuracy using age group (dummy coded in reference to 8- and 9-year-olds), post-error information-

seeking, and task accuracy during the information-seeking phase. Information-seeking phase accuracy served as a covariate to determine whether post-error information-seeking predicted final task accuracy above and beyond accuracy during the information-seeking phase. Follow up analyses using the same models were also conducted where post-*correct* information-seeking was included as a predictor as opposed to post-error information-seeking in order to confirm that our results were specific to information-seeking following errors.

In order to examine the relation between GPA and post-error information-seeking, we conducted regression analyses predicting GPA using post-error information-seeking and overall task accuracy. The inclusion of overall task accuracy allows us to determine whether post-error information-seeking predicted GPA above and beyond level of ability in the problem-solving task. Regression models examined retrospective (Time 1), prospective (Time 2), and change in GPA between Time 1 and Time 2 separately. Change was assessed by predicting GPA at Time 2 with GPA at Time 1 and overall task accuracy included as covariates. Additional exploratory analysis examined developmental differences by including age-group and the age-group by post-error information-seeking interaction.

2.5. Results

2.5.1. Preliminary analyses

The majority of students (79 %) completed all trials ($M = 13.96$, $SD = 2.24$ of 15 trials completed for Version 1 and $M = 14.60$, SD = 2.78 of 16 trials for Version 2). Fourteen students (7.2 %) were removed from analyses that involved task accuracy because they did not complete at least 2 trials during the final test phase; however, results remain significant when examining the data including all students ($ps < .04$, See Supplemental Materials). Additionally, the "I cannot solve this puzzle" response option occurred on only 3.39 % of trials, precluding us from conducting meaningful analysis of this measure. This opt out response was coded as an incorrect response. However, results remain significant if "I cannot solve this puzzle" responses were instead removed ($ps < .008$, See Supplemental Materials).

Overall accuracy was higher in task Version 1 ($M = .71$, $SD = .14$) compared to Version 2 ($M = .65$, $SD = .14$, $t(178) = 2.79$, $p = .006$). This result was expected given that Version 2 included more difficult puzzles. However, task version did not interact with any of the reported findings ($ps > .18$) and therefore results reported below did not further consider this factor.

2.5.2. Overall accuracy

Overall accuracy was significantly different across age groups, $F(2,177) = 21.41$, $p < .001$, $\eta_p^2 = .20$, such that 16- and 17-year-olds ($M = .75$, $SD = .11$) performed significantly better than 11- and 12-year-olds graders ($M = .65$, $SD = .13$, $p < .001$), who did not differ from 8- and 9-year-olds ($M = .61$, $SD = .14$, $p = .16$). These results demonstrate developmental improvements in task performance.

2.5.3. Information-seeking

We examined whether information-seeking was higher during incorrect relative to correct responses and whether this pattern was moderated by age group. There was a significant accuracy by age group interaction, $ps < .03$ (See Table 1, Fig. 2). Follow-up simple effects analyses demonstrated no age-related differences for information-seeking after incorrect responses ($ps > .49$); however, significant differences emerged for correct responses such that 8- and 9-year-olds sought significantly more tips when they got the puzzle correct than both 11- and 12-year-olds ($b = -1.12$, $p = .04$) and 16- and 17-year-olds ($b = -1.48$, $p = .003$), who did not differ from each other ($b = -.36$, $p = .43$). All age-groups sought significantly more tips following an incorrect relative to correct response ($ps < .001$). These results suggest developmental improvements in information-seeking such that older children and adolescents are less likely to seek tips when they are not as informative (i.e., after a correct response).

2.5.4. Post-error information-seeking and test accuracy

We examined whether greater post-error information-seeking correlated with increased accuracy during the final test phase, while controlling for puzzle-solving ability using accuracy from the information-seeking phase. Results revealed that post-error information-seeking was a significant positive predictor of test accuracy ($b = .13$, $p < .001$), above and beyond both information-seeking phase

Table 1
Study 1 multilevel model results predicting information-seeking.

	SD	b	95 % CI	SE	z	*Odds Ratio*	*p*
Random Effect							
Intercept	1.62						
Fixed Effect							
Intercept		1.46	[0.76, 2.16]	0.36	4.09	4.30	<.001
Accuracy		−1.94	[−2.88, −0.99]	0.48	−4.01	0.14	<.001
12- to 13-year-olds		0.12	[−0.85, 1.09]	0.50	0.24	1.12	0.81
16- to 17-year-olds		0.29	[−0.66,1.24]	0.48	0.60	1.34	0.55
Accuracy x 12- to 13-year-olds		−1.57	[−2.94, −0.20]	0.70	−2.25	0.21	0.02
Accuracy x 16- to 17-year-olds		−2.05	[−3.35, −0.76]	0.66	−3.11	0.13	<.01

*Note CI = Confidence Interval. Accuracy was coded as dichotomously (0-incorrect, 1-correct) and age group was dummy coded in reference to 8- and 9-year-olds.

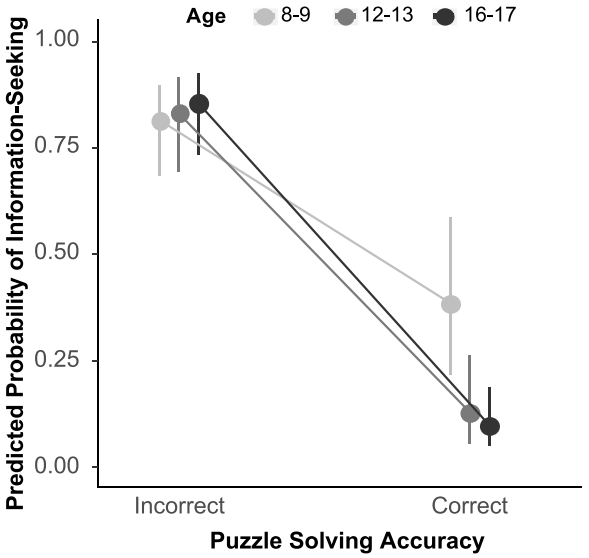

Fig. 2. Study 1 Predicted probability of tips sought after correct and incorrect responses by age group. Error bars represent 95 % confidence intervals.

accuracy ($b = .10, p = .09$) and age group (11- and 12-year-olds: $b = -.05, p = .15$; 16- and 17-year-olds: $b = .07, p = .03$). Overall, these results suggest that children who were more likely to seek information following an error also performed better during the final phase of the task.

To verify that our results were specific to information-seeking following errors, and did not pertain to information seeking generally, we conducted an additional multiple regression analysis that included post-*correct* information-seeking as opposed to post-error information seeking. Post-*correct* information-seeking was a not a significant predictor of test accuracy ($b = .04, p = .38$), while controlling for both information-seeking phase accuracy ($b = .03, p = .70$) and age group (11- and 12-year-olds: $b = -.03, p = .47$; 16- and 17-year-olds: $b = .08, p = .05$). These results suggest that information-seeking following errors, but not correct responses, was correlated with final test accuracy.

2.5.5. *Post-error information-seeking and academic achievement*

We examined whether post-error information-seeking predicted GPA while controlling for overall task accuracy in the two older age groups that had GPA available (See Table 2, for pairwise correlations see Supplementary Table 1). Post-error information-seeking significantly predicted both Time 1 ($b = .21, p = .01$) and Time 2 ($b = .22, p = .01$) GPA. Not surprisingly, post-error information-seeking was not significant ($b = 0.003, p = .85$) when predicting Time 2 GPA while controlling for Time 1 GPA and overall task accuracy, given that GPA at T1 and T2 was cumulative and highly correlated, $r = .98, p < .001$.

Exploratory analyses revealed that adding the main effect of age group and the age group by information-seeking interaction term did not significantly increase model fit for any model tested (*p*s>.11), suggesting that these effects were similar across early and late adolescents. Overall, results suggest that asking for helpful information following an error is associated with classroom academic achievement.

Finally, we conducted a follow-up multiple regression analysis that included post-*correct* information-seeking as opposed to post-error information seeking. Post-*correct* information-seeking did not significantly predict Time 1 GPA ($b = .02, p = .88$), Time 2 GPA

Table 2
Study 1 regression model results predicting GPA.

	b	95 % CI	SE	*t*	r_p	*p*
GPA Time 1						
Intercept	3.56	[3.22, 3.89]	0.17	20.88		<.001
Overall Task Accuracy	0.07	[−0.42, 0.56]	0.25	0.27	0.03	0.78
Post-Error Information-Seeking	0.21	[0.04, 0.37]	0.08	2.52	0.24	0.01
		Overall Fit: $R^2 = 0.06$, $F(2,107) = 3.69$, $p = 0.03$				
GPA Time 2						
Intercept	3.51	[3.17, 3.85]	0.17	20.48		<.001
Overall Task Accuracy	0.15	[−0.34, 0.65]	0.25	0.61	0.06	0.54
Post-Error Information-Seeking	0.22	[0.05, 0.38]	0.08	2.58	0.24	0.01
		Overall Fit: $R^2 = 0.08$, $F(2,104) = 4.33$, $p = 0.02$				

*Note CI = Confidence Interval.

(b=−.01, p = .92), or Time 2 GPA while controlling for Time 1 GPA (b=−.02, p = .35).

2.6. Study 2

The aim of Study 2 was to replicate the relation between academic achievement and post-error information-seeking using an independent, larger sample of 13- to 20-year-olds with greater ethnic and academic diversity.

2.7. Methods

2.7.1. Participants

A sample of 2922 students between 13–20 years of age (M_{age} = 16.41; SD = 1.14). This sample size was powered to detect a minimum correlation of .08 at $p < .05$. This sample was part of a larger project examining individual differences in partnership with the Character Lab Research Network (See Supplementary Material for more participant information; Porter et al., 2020).

Approximately 32 % of students were in 9th grade, 31 % were in 10th grade, 25 % were in 11th grade, and 12 % were in 12th grade. The sample was diverse in terms of race and ethnicity (43 % were Hispanic or Latino, 32 % were White, 18 % were Black, 5% were Asian, 2% were Multirace, 1% were Hawaiian/Pacific Islander, and 0.4% were American Indian), sex (53 % female), and academic ability (GPA ranged from 0 to 4.0; Fall 2017: M = 2.92, SD = .87, Spring 2018: M = 2.82, SD = 1.00). A majority of students (68 %) were eligible for free or reduced-price lunch as indicated by school records. This study was approved by University of Pennsylvania's institutional review board and qualified for a waiver of consent.

2.8. Materials and procedure

The materials and procedure were identical to Study 1 with the exception that all participants completed Version 1 of the behavioral task. The behavioral task was administered to students in January and February of 2018 and took students approximately 7 min to complete (Med = 6.53 min, SD = 4.08 min).

2.9. Measures

Accuracy, post-error information-seeking, and post-correct information seeking were measured the same as in Study 1.

2.9.1. Academic achievement

Grades were collected through deidentified school reports for four marking periods corresponding to quarters of the school year on a 100-point scale. Each marking period was distinct and not cumulative. An average grade was computed based on all classes for each marking period. Retrospective grades (Time 1) were measured as the average of the two marking periods during Fall 2017 and prospective grades (Time 2) were measured as the average of the two marking periods during Spring 2018. Grades were then converted to a standard 4.0 GPA scale (i.e., Grades 97–100 = 4.3; Grades 93–96.99 = 4.0; Grades 90–92.99 = 3.7, etc.) to ease comparison with Study 1.

2.10. Statistical analyses

Statistical analyses were identical to Study 1. Developmental effects were examined with age in years as a continuous measure based on self-report.

2.11. Results

2.11.1. Preliminary analyses

Fifty-seven percent of participants completed all trials (M = 12.55, SD = 3.01 of 15 trials completed). As in Study 1, for analyses involving overall or test phase accuracy, participants must have completed at least 2 trials during the final test phase consisting of both an easy and a difficult puzzle; this resulted in the removal of 451 (15.43 %) participants from analyses that involved task accuracy. However, results remained significant when examining the data including all participants (ps<.02, See Supplementary Materials). Additionally, the "I cannot solve this puzzle" response option occurred on only 2.5 % of trials and was coded as an incorrect response. However, results remain significant if "I cannot solve this puzzle" responses were instead removed (ps<.04, See Supplementary Materials).

2.11.2. Overall task accuracy

Overall proportion correct was M = .66, SD = .16. There was no significant correlation between age and proportion correct, r=−.02, p = .32.

2.11.3. Information-seeking

When we examined information-seeking on a trial-level, there was a significant main effect of accuracy, b=−2.83, p<.001 such that tips were sought more frequently following incorrect relative to correct responses. Age and the age by accuracy interaction were not

Table 3
Study 2 multilevel model results predicting information-seeking.

	SD	b	95 % CI	SE	z	*Odds Ratio*	*p*
Random Effect							
Intercept	1.00						
Fixed Effect							
Intercept		0.96	[−0.08, 2.00]	0.53	1.81	2.62	0.07
Accuracy		−2.83	[−4.45, −1.22]	0.83	−3.44	.06	<0.001
Age		−0.03	[−0.09, 0.03]	0.03	−0.93	.97	0.35
Age x Accuracy		0.05	[−0.05, 0.15]	0.05	0.98	1.05	0.33

*Note CI = Confidence Interval. Accuracy was coded as dichotomously (0-incorrect, 1-correct) and age (mean centered) was treated as continuous.

significant (*ps*>.32) (See Table 3). Thus, adolescents sought information more frequently following an incorrect relative to a correct response and this effect was similar across age.

2.11.4. Post-error information-seeking and test accuracy

Results revealed that post-error information-seeking was a significant positive predictor ($b = .12$, $p < .001$) of test accuracy above and beyond accuracy in the information-seeking phase ($b = .19$, $p < .001$) and age (mean centered) ($b = -.003$, $p = .35$). Overall, these results suggest that those adolescents who were more likely to seek information following an error also performed better during the final phase of the task.

Once again, we conducted an additional multiple regression analysis that included post-*correct* information-seeking as opposed to post-error information seeking. Post-*correct* information-seeking was a not a significant predictor of test accuracy ($b = .01$, $p = .43$), while controlling for both information-seeking phase accuracy ($b = .20$, $p < .001$) and age ($b = -.01$, $p = .11$).

2.11.5. Post-error information-seeking and academic achievement

Post-error information seeking was a significant predictor of academic achievement above and beyond overall task accuracy at both Time 1 ($b = 0.11$, $p = .01$) and Time 2 ($b = 0.13$, $p = .01$) (See Supplementary Table 2 for pairwise correlations). Additionally, exploratory analyses revealed that adding age (mean centered) and the interaction between age and post-error information-seeking significantly increased fit (*ps*<.04) (See Table 4). The interaction between age and post-error information-seeking was significant for both Time 1 ($b = -0.09$, $p = .01$) and Time 2 ($b = -.10$, $p = .03$) GPA, such that the relation between post-error information-seeking and GPA was stronger in younger relative to older adolescents (See Fig. 3).

Post-error information-seeking did not significantly predict GPA at Time 2 ($b = 0.03$, $p = .34$) when GPA at Time 1 was accounted for, suggesting that post-error information-seeking did not predict change in GPA. Once again this may be due to a high correlation between GPA at Time 1 and Time 2 ($r = .83$, $p < .001$).

Finally, we conducted an additional multiple regression analysis that included post-*correct* information-seeking as opposed to post-error information seeking. Post-*correct* information-seeking was a significant negative predictor of Time 1 GPA ($b = -.12$, $p = .008$), when overall task accuracy was controlled ($b = 1.30$, $p < .001$). This suggest that students with lower GPA at Time 1 may seek information more indiscriminately or to confirm what they already knew. However, post-*correct* information-seeking was not a significant predictor of Time 2 GPA ($b = -.05$, $p = .35$). Therefore, future research is needed to replicate the negative relation between GPA and post-*correct* information-seeking and we do not further interpret this finding. Adding age and the interaction between age and post-

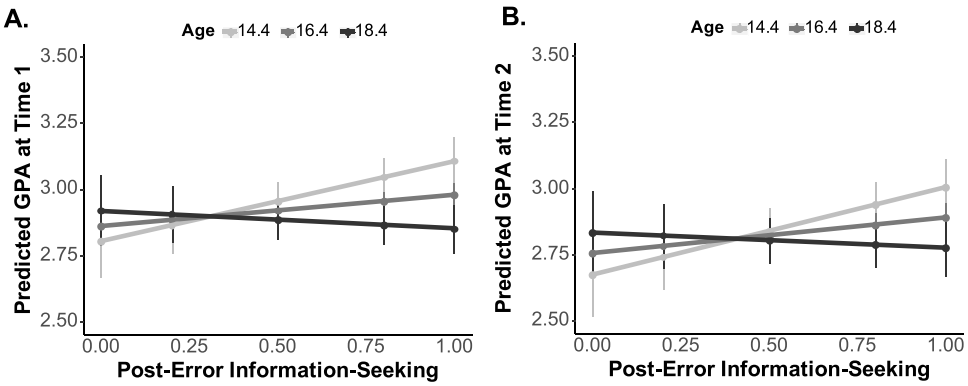

Fig. 3. Study 2 relation between post-error information-seeking and GPA by age. Post-error information-seeking rate and age interaction predicting A.) GPA at Time 1 and B.) GPA at Time 2. Age values represent mean age and +/- 2 years around mean age. Error bars represent 95 % confidence intervals.

Table 4
Study 2 regression model results predicting GPA.

	b	95 % CI	SE	*t*	r_p	*p*
GPA Time 1						
Intercept	2.20	[2.05, 2.35]	0.08	29.93		<0.001
Overall Task Accuracy	1.03	[0.79, 1.27]	0.12	8.44	0.17	<0.001
Post-Error Information-Seeking	0.12	[0.03, 0.21]	0.05	2.54	0.05	0.01
Age (centered)	0.03	[−0.03, 0.09]	0.03	0.99	0.02	0.32
Age x Post-Error Information-Seeking	−0.09	[−0.17, −0.02]	0.04	−2.45	−0.05	0.01
		Overall Fit: R^2 = 0.05, F(4, 2289)= 29.10, p < 0.001				
GPA Time 2						
Intercept	2.18	[2.01, 2.35]	0.09	24.61		<0.001
Overall Task Accuracy	0.89	[0.61, 1.17]	0.14	6.25	0.13	<0.001
Post-Error Information-Seeking	0.13	[0.03, 0.24]	0.05	2.50	0.05	0.01
Age (centered)	0.04	[−0.03, 0.11]	0.03	1.17	0.02	0.24
Age x Post-Error Information-Seeking	−0.10	[−0.18, −0.01]	0.04	−2.18	−0.05	0.03
		Overall Fit: R^2 = 0.03, F(4, 2295)= 17.62, p < 0.001				

*Note CI = Confidence Interval.

correct information-seeking did not significantly increase model fit for Time 1 or Time 2 GPA (*ps*>.06).

3. Discussion

The goal of this research was to examine developmental differences in children and adolescents' information-seeking behaviors and its relation to classroom academic achievement. We focused on assessing students' information-seeking after making errors, as this may be especially useful for capturing students' motivation to improve their learning. We found post-error information-seeking to be positively associated with both final task performance and classroom academic achievement. This suggests that objective measures of information-seeking can provide useful information about students' behaviors and learning outcomes.

3.1. Development of information-seeking

We found that children as young as 8- to 9-years-old demonstrated adaptive information-seeking, such that they were more likely to seek tips following errors compared to correct responses. This finding is consistent with metacognitive literature demonstrating that children can appropriately self-reflect about their accuracy and guide their decision-making by middle childhood (Ghetti et al., 2011; Roebers, 2002). Metacognition continues to improve into adolescence (Fandakova et al., 2017) and older children are also more adept at asking for help when experiencing lower confidence (Nelson-Le Gall et al., 1990), motivating the hypothesis of persisting improvements in adaptive information-seeking beyond childhood. Consistent with this hypothesis, we found that 11- and 12-year-olds and 16- and 17-year-olds were less likely to ask for tips following correct responses than were 8- to 9-year-olds, underscoring greater efficiency in older children and adolescence when it comes to seeking additional information in situations where it may be less beneficial. In the current task there was no penalty associated with asking for additional information and multiple strategies could be used to arrive at the same conclusion. Therefore, it is possible that young children may have sought help during correct responses to explore other potential strategies. However, if younger children were generally more curious to explore strategies, we would have anticipated higher information-seeking across both correct and incorrect responses, which is not what we observed. Future work should assess whether the same pattern of results would be observed when there is a limit to the number of times children can seek help. Furthermore, the current study included three trials during the information-seeking phase based on previous research validating the current task (Porter et al., 2020) and in order to make the task feasible for self-administration in a classroom setting. Future work could examine if greater developmental differences would be observed when using additional trials, which may capture more fine-grained differences in information-seeking.

Although we found that 11- and 12-year-olds and 16- and 17-year-olds were more efficient than younger children at information-seeking, other research suggest that older children often report avoiding seeking information when they really need it (Newman, 2000; Ryan & Shim, 2012). This decline in information-seeking is in part due to children becoming more sensitive to the perceived social costs and benefits associated with asking for help (Gonida et al., 2014). In the current study, we examined objective information-seeking behaviors when there was no explicit social cost or benefit. Manipulations of social contexts may be helpful to elucidate the circumstances under which older children and adolescents may behave in maladaptive information-seeking. Although older children tend to improve their decision-making when they attempt to incorporate additional information in contexts during which peers are not present (Betsch & Lang, 2013), we may observe declines with age as children increase their sensitivity to potential social costs (e.g., embarrassment) when peers or others can observe help-seeking behaviors (Ryan & Pintrich, 1997).

3.2. Post-error information-seeking and academic achievement

Information-seeking has been linked to classroom achievement in children and adolescents (Ryan & Shim, 2012; Ryan & Shin,

2011; Ryan et al., 2005). Here, we focused on how children seek additional information following explicitly known errors, which captures students' attempts to learn additional information that can help with their future performance and learning. We observed that post-error information-seeking was positively associated with final test performance and classroom GPA, above and beyond task accuracy. Furthermore, the relation was not observed when we correlated post-*correct* information-seeking and test performance and classroom GPA. Overall, these results suggest that seeking information following errors is a particularly adaptive strategy that captures variance in immediate and broader, long-term learning, independent of matrix reasoning skills. We replicated these findings across two data sets that varied in diversity in terms of age, race and ethnicity, and academic achievement. Additionally, exploratory analyses revealed that this relation was stronger in younger compared to older adolescents. It is possible that as adolescents develop improved strategies to regulate their learning (Zimmerman & Martinez-Pons, 1990), post-error information-seeking is perhaps not as important for academic achievement and instead other factors (e.g., allocation of study time) play a more important role. Future research should replicate this exploratory finding and also measure multiple self-regulation strategies to examine if different strategies change in their contribution to academic achievement across development when information-seeking is also measured. Nevertheless, participants' tendency to seek additional information in problems that cannot be corrected suggests that this behavior may capture tendencies towards improvement that extend beyond currently necessary information and, for this reason, may be associated with academic achievement more broadly. Additionally, we demonstrate this relation using an online task in which children sought information in the absence of social interactions, suggesting that information-seeking behaviors even in remote learning environments demonstrate a positive association with broader learning outcomes.

The relation between post-error information-seeking and academic achievement was small to medium in effect size. Academic achievement is a multidimensional measure and recent work has emphasized interpreting effect size in terms of practical significance (Funder & Ozer, 2019). Our effect sizes are consistent with those reported in other work on relations between self-regulated learning and GPA (Ryan & Shim, 2012; Sperling, Richmond, Ramsay, & Klapp, 2012), as well as other research that examines correlations between GPA and behavioral tasks (Galla et al., 2014; Meindl et al., 2019). Our research suggests that students who consistently ask for help following mistakes have a higher GPA of approximately 0.2 points, which in practical terms translates into half a letter grade (e.g., B vs. B+). Our results also replicated across different sample sizes and US populations, improving the reliability and generalizability of our findings.

We did not find post-error information-seeking to predict change in GPA across time. However, our assessments of GPA were strongly correlated, collected on a relatively short time scale (~1 year), and measured for only older children and adolescents, limiting our ability to capture meaningful differences across time. Thus, future work is needed to assess the role of information-seeking on academic achievement in younger children and longitudinal changes across a larger time scale.

In conclusion, the current research underscores the importance of examining whether and how children seek information after making mistakes, and how this tendency may be integral to academic achievement. Our results demonstrate that children become more efficient in their information-seeking as they become older, and seeking information following mistakes positively correlates with later task performance and academic achievement. Overall, this research contributes to our understanding of how children and adolescents become self-regulated learners.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.cogdev.2021.101062.

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