The Relation Between Academic Achievement and the Spontaneous Use of Design-Thinking Strategies

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Abstract

Design-thinking strategies are believed to enhance performance and learning, but it is unclear whether these strategies have any relation to the types of learning measured by tests of academic achievement. This study examines the relations between students' prior academic achievement, their choices to use design-thinking strategies of seeking critical feedback and revising their work, and their learning during a 10-15-minute on-line activity. Sixth-grade students designed three digital posters. After each poster, they had chances to seek either critical or confirmatory feedback, followed by a chance to revise the poster or not. Results show that prior academic achievement is positively related to students' spontaneous use of critical feedback-seeking. Critical feedback-seeking is positively associated with students' performance on the poster design task through revising, regardless of prior academic achievement. Thus, prior academic achievement indirectly predicts performance, first through critical feedback-seeking and then through revising. One possible interpretation is that students who exhibit higher academic achievement attained those levels because they had spontaneously employed these strategies during their academic studies. To test this claim, future work needs to determine if instruction in design-thinking strategies increases student academic achievement.

Keywords: feedback-seeking; revising; performance; academic achievement; assessment; design thinking

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Introduction

Design-thinking strategies and attitudes have been advanced as a response to the growing complexity of the 21st-century problems that workers will need to solve (Goldman & Kabayadondo, 2017). Design-thinking behaviors, such as seeking constructive criticism and revising one's work, are powerful problem-solving strategies that prevent people from settling prematurely on less effective solutions. Ideally, design thinking can help students to solve problems in unstructured learning domains outside their classrooms, when guidance may be absent and they need to adapt to tackling the challenges of an ever-changing world surrounding them.

There is increasing consensus that instructional efforts should target both the curriculum content and the strategies required to learn this content (Bransford, Brown, & Cocking, 1999). This way, students can continue to learn and grow beyond school. For instance, the learning by design (LBD) theory concomitantly takes into account the learning of cognitive, social, learning, and communication skills. LBD curricula emulate the practices of experts (e.g., scientists, designers, etc.) that students can ideally carry with them into the "real" world. Empirically, the LBD approach has been found to promote learning in middle-school science classrooms (Kolodner, 1997; Kolodner et al., 2003).

Design thinking has also been advanced as an antidote to overly regimented curricula that funnel students down a narrow path of right and wrong answers (Chin et al., 2019). This implies that design-thinking strategies do not find regular expression in typical schools, as traditional instruction may tend to focus on simplified scenarios that are often esoteric and devoid of meaning (Kolodner et al., 2003). If true, one would predict that there is little relation between students' academic achievement and their use of design-thinking strategies. Alternatively,

students may still find ways to use design-thinking strategies to learn in school, even if they are not engaged in full-blown design activities. For instance, students may seek constructive criticism and revise their work based on that criticism. In this case, one would predict that students with higher academic achievement are more likely to use these design-thinking strategies, because these strategies purportedly support learning.

The present study aims to explore the relations among prior academic achievement, spontaneous use of the two design-thinking strategies of seeking critique and revising, and performance in a brief on-line activity. Our leading hypothesis is that prior academic achievement will positively correlate with the choice to seek critical feedback and revise, and that the spontaneous use of these strategies will lead to better performance in the activity. To address this hypothesis, we conducted a series of mediation analyses on data collected from 6th-grade students as part of a previously reported study (Chin et al., 2019). The study also highlights the use of a choice-based assessment (Posterlet) in the context of measuring the extent of students' design-thinking strategies (viz., critical feedback-seeking and revising one's work) for problem solving and learning. Choice-based assessments measure whether students use select strategies, even when there are no cues or instructions to use a given strategy.

Design-Thinking Choices and Learning

Design thinking comprises many strategies ranging from the empathetic to the iterative (Goldman & Kabayadondo, 2017). In focus here is the familiar mantra to "fail early, fail often." The purpose of this mantra is to accustom individuals to the idea that failure is an acceptable, and even embraced, part of the design process. The mantra entails two key strategies. The first is that failure provides important critical feedback. It provides hints where solutions could be improved or when problems are intractable. The second is that revision is an important part of the design

process, so it is possible to improve on one's original designs. The present work looks at whether students choose to use the two strategies of seeking critical feedback and revising one's work. Students make these choices in the context of a computerized design task of creating posters for a fair. Notably, these two strategies may also be useful in traditional school tasks that do not involve design and, therefore, student choices in the design task may exhibit associations with academic achievement.

In general, feedback improves learning and performance, but it depends on what and how it is delivered (Kluger & DeNisi, 1998). For instance, feedback targeted at a task performance (e.g., "this product could be prettier") is more effective than feedback targeted at a person (e.g., "you should have made the product prettier"; Hattie & Timperley, 2007; Kluger & DeNisi, 1998). Constructive criticism tends to improve learning compared to praise, because praise signals that the work is good enough, whereas constructive criticism points to places for improvement. For instance, misguided feedback may result in lower motivation and performance outcomes (Faichney & Kelly, 2019) and peer-to-peer feedback can cause discomfort, as it could highlight one's shortcomings (Twenge, 2009). People often shy away from critical feedback to protect their egos (Chase, Chin, Oppezzo, & Schwartz, 2009; Kluger & DeNisi, 1998; Kulik & Kulik, 1988).

Most studies on feedback have considered supervised learning, where another person or computer delivers the feedback to the students, whether they want it or not. It is a strong legacy of the behaviorist tradition (Thorndike, 1927). The current work examines how students make choices about receiving feedback. This is important for the question of whether students spontaneously choose to use the design-thinking strategy of seeking critique, when there is not strong enforcement of a feedback schedule. Moreover, seeking constructive criticism may be an

effective way to learn. For instance, feedback-seeking was associated with enhanced teaching performance in pre-service teachers (Harwood & Froehlich, 2017).

The decision to revise one's work has been associated with enhanced performance and learning (Cutumisu, Blair, Chin, & Schwartz, 2015). Deciding against revising one's work may signal a propensity to commit to one's first idea prematurely, which has been shown to lead to poorer performance in artistic tasks (Csikszentmihalyi & Getzels, 1970). In contrast, deciding to revise one's work may lead to fixing current mistakes or discovering new ideas, with the potential of leading to a more effective performance. Revising one's work takes extra effort, time, and a willingness to restart, so there are natural barriers to revision. Yeager et al. (2014) found that high-school students often did not revise essays based on constructive criticism, unless the feedback began with a message explaining that the teacher had great confidence in the students' abilities to improve and that's why they were providing the feedback. Thus, like constructive criticism, there are strong reasons to believe that revision can support learning, but there are natural psychological and situational barriers that may lead students away from choosing to revise. The question is whether high-achieving students are more likely to choose to seek revision (and constructive criticism) than low-achieving students. More specifically, will high-achieving students seek constructive criticism at a higher rate and does the criticism drive them to revise more?

Method

Participants and Procedure

The participants were 97 sixth-grade middle-school students from a public school in California (46 females, 51 males). Students played the Posterlet game individually (Cutumisu, Blair, Chin, & Schwartz, 2015), in which they designed three posters for booths at a Fun Fair.

They had no prior experience with Posterlet and no formal digital poster design experience. Only n = 80 students (39 females and 41 males) provided both assent and parental consent, and also completed the Posterlet game (M = 13.57 minutes, SD = 5.73). This sample was drawn from a prior experiment that examined whether students can learn and spontaneously transfer design-thinking strategies, including seeking constructive criticism and exploring a space of alternatives (Chin et al., 2019). For five weeks, researchers and classroom teachers provided design-based instruction to students at their school in the math classes (two weeks), science classes (one week), and social studies classes (three days) that highlighted the teaching of both curriculum content and design-thinking methods, as detailed in prior work (Chin et al., 2019). The current work is a further analysis of a subset of the data using only students for whom we had complete pre- and post-tests, complete achievement data, and who never received instruction on seeking constructive criticism or revising (i.e., students belonged to the condition in which they were taught to explore a space of alternatives). Specifically, students in this condition produced several instances of designs (e.g., 3D boxes, a scale model of a house, etc.), then they compared and discussed these instances with their peers or instructors (i.e., researchers and teachers) to determine their essential properties.

Primary Measurement Instrument: Posterlet

To determine whether students choose specific design-thinking strategies, we created Posterlet (Cutumisu, Blair, Chin, & Schwartz, 2015), a computer-based assessment game that collected students' learning analytics while they were designing digital posters. The aim of this short assessment (i.e., 10-15 minutes) was to track students' choices and performance in a novel environment that did not resemble a school-based activity, to be able to measure the transfer of learning. The narrative of Posterlet is that players need to design three digital posters for a fair by

choosing from five different themes (e.g., basketball toss, pie baking, light it up, bubbles science, and estimation station, as shown in Figure 1).

Each poster provides an initial blank canvas on which players can place two types of entities: images (e.g., graphics related to the five themes of the game, such as a light bulb, as shown in Figure 2) and text (e.g., "Come to the Fall Fun Fair!", as shown in Figure 3). Then, after designing each poster, students were required to choose between receiving either confirmatory or critical feedback from a focus group of three virtual animal characters, asking each character for either critical ("I don't like…") or confirmatory ("I like …") feedback, as shown in Figure 4. There was no option to skip the feedback. The game tracks the number of times that each player chooses critical versus confirmatory feedback. Thus, the amount of critical feedback ranges from zero (i.e., the player is only interested in confirmatory feedback about the current poster) to nine (i.e., the player is only interested in critical feedback about the current poster). Then, students had a choice to revise each of their posters, so the game also tracks the number of posters each player chooses to revise. For each poster, after receiving feedback, students decide whether to submit their poster as it is or to revise it, which they can do only once per game round. Thus, the amount of revisions ranges from zero (i.e., the player decided to not revise any posters) to three (i.e., the player decided to revise all three posters).

The game also tracks students' poster quality and displays it as the number of tickets sold at each booth. The game computes this measure by comparing each poster against a set of 21 graphic design principles provided by a professional graphic designer. The feedback messages are generated as a result of this comparison process, according to an intelligent feedback system (Cutumisu, Blair, Chin, & Schwartz, 2017) that prioritizes the feedback by cycling through three categories of design rules: essential information (e.g., the location of the fair should be included

on the poster canvas), readability (e.g., the text should be large enough to read from a distance), and space use (e.g., the poster should not be half empty). This process is repeated for each of the three rounds of the game. The sum of the measures of poster quality across the entire game represents the overall performance on the Posterlet game.

Measures

Design-Thinking Choices. Posterlet enabled the tracking of students' two choices of interest across the game. First, *Critical Feedback-Seeking* represents the number of times students choose critical feedback across the game. It ranges from zero to nine, as students had three opportunities to seek critical feedback on each of the three game rounds. Although students' confirmatory feedback choices were not explicitly tracked, the two feedback-seeking measures are complementary. Thus, a significant positive correlation with Critical Feedback-Seeking translates into a significant inverse correlation with Confirmatory Feedback-Seeking.

Second, *Revision* represents the number of posters students choose to revise across the game. It ranges from zero to three, as there was just one opportunity to revise one's poster on each of the three game rounds.

Performance Outcomes. *Performance* represents the overall poster quality across the game, summing up the poster quality of the last poster on each game round (i.e., either the first draft, if the student did not choose to revise the poster on that round, or its revision, if the student chose to revise the poster on that round). *Pre-test* represents the quality of the first poster, before any revisions. *Performance Gain* represents the difference between students' overall poster performance across the game and the *Pre-test*. This measure is useful, as it will enable us to quantify whether the pre-test cancels out or not the effect of academic achievement on students' overall poster performance.

Prior Academic Achievement. Complete Mathematics (*Math*), Science (*Science*), and English Language Arts (*ELA*) from the *Standardized Testing and Reporting (STAR) California Standards Tests (CST)* were available for all the participants. These tests were administered for the year before the current study was conducted. All achievement scores were combined to make a single *Achievement* index, with higher scores representing higher achievement. The reliability of this construct is satisfactory (i.e., the omega coefficient of .78 exceeds the .7 threshold, indicating satisfactory reliability; Dunn, Baguley, & Brunsden, 2014).

Data Analyses

Descriptive analyses, correlations, and regressions were conducted to analyze the hypothesized Model 1 (critical feedback-seeking → revision → performance, controlling for the pre-test and gender) and Model 2 (critical feedback-seeking → revision → performance gain, controlling for gender), respectively. As there was a possibility that students' prior academic achievement influenced students' design-thinking choices, learning outcomes, and the relation among these measures, structural equation modelling (SEM) analyses were conducted to examine the causal relations between design-thinking choices and performance, controlling for prior academic achievement, pre-test, and gender: the hypothesized mediation was represented by Model 3 (students' prior academic achievement → critical feedback-seeking → revision → performance, controlling for pre-test and gender). Finally, SEM analyses were also conducted to examine the causal relations between design-thinking choices and performance gain, controlling for prior academic achievement and gender: the hypothesized mediation was represented by Model 4 (students' prior academic achievement → critical feedback-seeking → revision → performance gain, controlling for gender).

Results

Descriptive Analyses

The descriptive statistics of the key variables included in this study are presented in Table 1. First, the assumptions for our analyses were tested. Except for females significantly outperforming males on their poster designs as well as on their gain in poster performance across the game, there were no significant gender differences on any of the key variables. Therefore, gender (1-female, 2-male) was only included in the analyses pertaining to performance and performance gain. Based on the sample size and correlations, we calculated the power for each mediation model (Schoemann, Boulton, & Short, 2017). The observed power value for the indirect effects for Model 1 was .40, for Model 2 it was .52, for Model 3 it was .43, and for Model 4 it was .60.

Correlations

Pearson bivariate correlations among the key variables of this study were conducted and the correlation coefficients are reported in Table 1. Findings revealed that prior academic achievement was associated with both design-thinking choices (critical feedback-seeking and revision). The findings also revealed that critical feedback-seeking was strongly and positively correlated with revision. In contrast with critical feedback-seeking, revision was associated with performance. Also, the pre-test was associated with performance, thus, it was included as a covariate in the models involving performance.

Regression Analyses

To test the hypothesized Model 1, a regression analysis was conducted using the PROCESS macro (Hayes, 2012) in SPSS (2017) to ascertain whether revision mediated the relation between critical feedback-seeking and performance. Figure 5 shows a significant total

effect of critical feedback-seeking on performance, controlling for gender and pre-test (R^2 = .45, b = 1.06, SE = .44, t = 2.43, p = .02, 95%CI = [.189, 1.925], β = .21), where the effect size represents the β coefficient of the standardized total effect. Furthermore, revision fully mediated the link between critical feedback-seeking and performance (R^2 = .48, b = .57, SE = .28, 95%CI = [.044, 1.177], β = .11), controlling for gender and the pre-test, where the effect size represents the β coefficient of the standardized indirect effect. This is due to the link between critical feedback-seeking and performance being no longer significant (R^2 = .48, b = .48, SE = .51, t = .95, p = .35, 95%CI = [-.531, 1.495], β = .09), where the effect size represents the coefficient of the standardized direct effect. Finally, the choice to revise posters predicts students' performance both initially and after accounting for the influence of gender and pre-test, albeit slightly less strongly. Specifically, the results shown in Figure 5 indicate that, for every standard deviation increase in students' choice to revise their posters, there is a .21 standard deviation increase in students' overall poster performance. Also, critical feedback-seeking still predicted students' choices to revise their posters, even after controlling for gender and pre-test, which is a constant finding across many studies sampling populations ranging from middle school to adulthood (Chin et al., 2019; Cutumisu, Blair, Chin, & Schwartz, 2015, 2017). The results shown in Figure 5 indicate that, for every standard deviation increase in critical feedback-seeking, there is a .54 standard deviation increase in students' choice to revise their posters. Furthermore, gender inversely predicted performance, with females improving their overall poster performance more than males. Taken together, the results indicate that revision is the mechanism through which critical feedback-seeking enhances performance, as it seems to fully explain the relation between critical feedback-seeking and performance.

Similarly, Model 2 was built to explore whether revision mediated the relation between critical feedback-seeking and performance gain. Figure 6 shows a significant total effect of critical feedback-seeking on *performance gain*, controlling for gender (R^2 = .18, *b* = 1.03, *SE* = .43, *t* = 2.36, *p* = .02, 95%CI = [.162, 1.893], β = .24). This model confirmed that revision fully mediated the link between critical feedback-seeking and performance gain, controlling for gender (R^2 = .23, *b* = .57, *SE* = .29, 95%CI = [.057, 1.205],β = .14), as the link between critical feedback-seeking and performance gain was no longer significant (R^2 = .23, *b* = .46, *SE* = .51, *t* = .90, *p* = .37, 95%CI = [-.557, 1.468], β = .11). Finally, the choice to revise posters predicted students' performance gain both initially and after accounting for the influence of gender, albeit slightly less strongly. As in the previous model, critical feedback-seeking still predicted revision, even after controlling for gender. Finally, gender inversely predicted performance gain, with females improving their gain in performance more than males from the beginning to the end of the game. Taken together, these results confirm those of Model 1, indicating that revision is the mechanism through which critical feedback-seeking enhances students' gain in performance.

Structural Equation Modelling

To test the hypothesized Model 3 and Model 4 as well as the associations among the key variables of this study more holistically, *Mplus 7.0* (Muthén & Muthén, 1998-2011) was employed. Results showed that Model 3 fit the data well (χ^2 = 19.95, *df* = 16, *p* = .22, CFI = .97, RMSEA = .06, SRMR = .09). The path coefficients for Model 3 are presented in Table 2 (non-standardized coefficients) and Figure 7 (standardized coefficients), where the solid black arrows represent statistically-significant paths and the grey dashed arrows represent non-significant paths. The values on the arrows represent standardized *β* regression coefficients. Similarly, results showed that Model 4 fit the data well (χ^2 = 10.94, *df* = 11, *p* = .45, CFI = 1.00, RMSEA =

.00, SRMR = .05). The path coefficients for Model 4 are presented in Table 3 (non-standardized coefficients) and Figure 8 (standardized coefficients).

The relation between design-thinking choices

Is critical feedback-seeking predictive of students' revision choices beyond prior academic achievement?

Findings are depicted in Model 3 (Figure 7). As in Model 1, only critical feedback-seeking significantly predicted revision, even after controlling for prior academic achievement. Thus, the correlation between critical feedback-seeking and revision is not critically influenced by academic achievement.

The relation between design-thinking choices and prior academic achievement

Does prior academic achievement influence students' critical feedback-seeking and revision choices?

Initially, prior academic achievement was positively associated with both design-thinking choices, as shown in Table 1. Results of the SEM analyses, illustrated in Figure 7 and Figure 8, showed that achievement still positively predicted critical feedback-seeking directly but it no longer predicted students' choices to revise their work. This suggests that students who perform better academically (i.e., on Mathematics, Science, and English Language Arts standardized tests) also seek critical feedback more often but they do not revise their posters more.

Moreover, findings revealed that prior academic achievement indirectly predicted revision through critical feedback-seeking (R^2 = .33, b = .03, SE = .08, 95%CI = [.01, .15], β = .20), as critical feedback-seeking fully mediated the relation between prior academic achievement and revision. That is, critical feedback-seeking fully explains the link between prior academic achievement and revision.

The relation between design-thinking choices and performance

Does revision influence students' performance, beyond their prior academic achievement?

The SEM analysis also revealed that revision still predicted performance, even after controlling for students' prior academic achievement. Thus, the correlation between revision and performance is not critically influenced by academic achievement.

Is revision explanatory of the mechanism that links students' critical feedback-seeking and performance, beyond their prior academic achievement?

We applied 5,000 bootstrap samples to test whether critical feedback-seeking indirectly predicted performance through revision (i.e., whether revision is the mechanism that links critical feedback-seeking and performance), while controlling for the covariates. Results were consistent with Model 1. Moreover, Model 3 revealed that revision fully mediates the relation between critical feedback-seeking and performance, beyond the influence of students' prior academic achievement (R^2 = .51, b = .55, SE = .26, 95%CI = [.13, 1.18], β = .11).

The Relation Between Prior Academic Achievement and Performance

The SEM Model 3 shows that none of the learning behaviors alone mediates the relation between students' prior academic achievement and performance. This model shows that revision does not mediate the relation between prior academic achievement and performance (R^2 = 51, b = .07, SE = .19, 95%CI = [-0.02, 0.57], β = .05), after controlling for the pre-test and gender. Given that critical feedback-seeking was not initially associated with performance, findings confirmed that critical feedback-seeking does not mediate the relation between prior academic achievement and performance (R^2 = .51, b = .09, SE = .19, 95%CI = [-.04, .52], β = .06), after controlling for the pre-test and gender.

Is prior academic achievement predictive of students' performance?

Although prior academic achievement does not directly predict performance, we found that achievement indirectly predicts performance, first through critical feedback-seeking and then through revision; the indirect effect of "achievement → critical feedback-seeking → revision → performance" controlling for gender and pre-test is significant (R^2 = .51, *b* = .07, *SE* = .16, 95%CI = [.014, .462], β = .05).

Similar results were obtained from Model 4, where the relations between design-thinking choices and performance gain were investigated, controlling for gender and prior academic achievement.

Discussion, Limitations, and Future Work

Taken together, the results revealed by this study show that students' design-thinking choices are more important for their performance than their prior academic achievement in Mathematics, Science, and English Language Arts. Moreover, the correlations between the two design-thinking choices as well as between revision and performance are not critically influenced by prior academic achievement. Specifically, critical feedback-seeking is more important for achieving a better performance in a new task domain (i.e., designing advertisement posters) than only revising one's work or only entering the task with higher prior academic achievement. Critical feedback-seeking significantly predicts revision, even after controlling for prior achievement, fully explaining the link between prior academic achievement and revision. Although revision fully mediates the relation between critical feedback-seeking and performance beyond prior academic achievement, the path analysis model revealed that it is critical feedback-seeking that is driving students' choice to revise and its relations with prior achievement and current performance. Finally, although prior academic achievement does not directly predict performance, it indirectly predicts performance through both design-thinking choices (i.e., first

through critical feedback-seeking and then through revision). Revision is likely to be correlated with performance, because performance is based on the quality of the submitted posters that benefitted from the revision. Presumably, revised posters would be better after critical feedback, because learners could address the specific critiques in their revisions. Although critical feedback-seeking is a key aspect of performance, it does not automatically imply the choice to revise one's work. Thus, if learners chose not to revise a poster, then their performance on that poster would not have a chance to improve and reflect the effect of critical feedback. This study shows that critical feedback enhances performance through revision, beyond prior academic achievement. Thus, together, critical feedback and revision are important for achieving better performance.

Results also indicated that prior academic achievement predicted students' choices to seek critical feedback, even after controlling for gender and the pre-test. This result was echoed by a previous study sampling nearly 500 middle-school students in New York City and Chicago (Cutumisu, Blair, Chin, & Schwartz, 2015). The study showed that students' critical feedback-seeking correlated with their poster performance, learning of graphic design principles, and their standardized test scores in Mathematics and Reading in each state. The current results provide more evidence in yet another state, California, with its own standardized achievement tests, that critical feedback-seeking is positively associated with students' performance and academic achievement and that its effect is generalizable.

In sum, critical feedback-seeking is positively associated with students' performance on school tasks (as measured by achievement) and non-school tasks (as measured by Posterlet), thus providing a window into how students will tackle new problems on their own. Similar results were found by other researchers in the domain of help-seeking. For instance, the present result is

consistent with other findings showing that students with better prior academic achievement tend to seek help from teachers and peers more frequently in both middle-school (Ryan & Shin, 2011) and university students (Hao, Wright, Barnes, & Branch, 2016). Moreover, middle-school students' first-quarter grades and academic self-efficacy were directly associated with adaptive help-seeking and inversely associated with avoidant help-seeking. It is possible that students demonstrating lower prior achievement are more likely to display lower self-efficacy when engaging in learning activities (Zhan & Mei, 2013).

Many previous studies found that prior achievement (i.e., knowledge) promoted better learning performance (Chou & Wang, 1999; Pintrich, Cross, Kozma, & McKeachie, 1986; Szajna & Mackay, 1995). For instance, prior mathematics achievement and verbal skills predicted computer skill performance (Cafolla, 1987). The current result shows a more nuanced take on the common belief that "success breeds success" where individuals' prior achievements predict their present and future achievements. Specifically, this study shows that prior achievement does not directly promote better learning performance in poster design, but rather it does so indirectly, through feedback and revision.

The SEM analyses were also conducted without controlling for gender. In that case, the total effect of revision on the relation between critical feedback-seeking and performance was still significant (i.e., revision still fully mediates the relation between critical feedback-seeking and performance, when controlling just for the pre-test), while for performance gain the total effect was marginally significant ($p = .06$).

Limitations

First, although the study employs structural equation modelling to explore the mediation effect of several key variables, the study is still correlational, so no causal inferences can be

definitively drawn. For instance, it could be that students' in-school, spontaneous use of critical feedback-seeking has an impact on their academic achievement in Mathematics, Science, or English Language Arts. That is, students' critical feedback-seeking behavior may be what is driving academic achievement and not the other way around. The way students behave in the Posterlet assessment game may reflect the kinds of activities they had been undertaking in school that could also lead to their current level of academic achievement (Chin et al., 2019). Specifically, the stance of the present study is that learning to make effective design-thinking choices is in fact a product of 21st-century instruction for innovation, which aims to prepare students for future learning (Bransford & Schwartz, 1999). One implication of this assertion is that choices constitute a first-order learning outcome that should be taught and assessed explicitly (i.e., students' design-thinking choices may be considered measures of learning and transfer, as much as, and perhaps even more than, summative assessment measures). As such, Posterlet is a dynamic assessment (Vygotsky, 1997) with a dual purpose: first, to facilitate the assessment of students' design-thinking choices and, second, to concomitantly assess students' performance outcomes as a result of their choices (Feuerstein, 1979). To explore this proposal more deeply, a recent experimental study explored the relation between critical feedback and learning outcomes when feedback was chosen versus being assigned to students (Cutumisu & Schwartz, 2018). The results showed that there were no differences in the choice to revise and in students' learning outcomes between conditions, emphasizing the powerful effect of critical feedback, regardless of being a choice. Relating these two studies seems to indicate that anyone, not only those who have a propensity to seek critical feedback or who perform better academically, may reap the benefits of critical feedback and revising to improve their

performance, as the same amounts of critical feedback led to the same levels of learning outcomes.

Second, although the sample size was appropriate for the analyses employed in this study, more data points will be collected in the future and the same analyses will be conducted to compare the results. Also, the revising behavior of other populations (e.g., college students) may influence the results differentially, so future research will investigate whether the current results can generalize to other demographics. In the meantime, as mentioned earlier, our results echoed the findings of a similar study sampling more than 200 middle-school students (Chin et al., 2019). However, the current analyses go beyond those of the previous study, as they include the exploration of the role of revision in the context of students' performance outcomes.

Third, other factors could explain the presence or absence of significant associations among the key variables included in this study. For instance, mindset, grit, or other motivational factors have not been measured in this study but it is possible that they may influence students' application of design-thinking choices to improve their performance.

Implications and Educational Significance

Theoretical Implications

The results revealed by this study have theoretical ramifications in elucidating how critical feedback-seeking enhances performance through revision in a creative, open-ended, digital poster-design task that affords many different solutions (i.e., there are many ways to design posters) regardless of which choices students make in the game. This study demonstrated that students' revising behavior explains the mechanism through which they perform better after seeking critical feedback, above and beyond their prior academic achievement. This is an important result, as it reveals a concrete strategy to improve one's performance that could be

taught and enhanced, rather than relying on inherent individual dispositions, attitudes, or abilities. This study has focused on performance rather than learning. However, it is possible that the connection of learning to critical feedback-seeking and revision is more interesting. For example, one might propose that revision is necessary to cement the learning from the critical feedback.

Moreover, prior academic achievement predicts students' choices to seek critical feedback but not their choices to revise their posters, while the relation between revision and achievement is fully explained by critical feedback-seeking. Thus, students with higher prior academic achievement revised more *because* they chose critical feedback more often. Also, the findings show that critical feedback-seeking is associated with historical achievement in school. The results show that it is the higher-achieving students who seek critical feedback the most, rather than the lower-achieving students who would presumably benefit from critical feedback the most. Future research studies could examine why there is a difference in critical feedback choices between higher and lower achievers. It could be that high achievers have had more practice with seeking critical feedback and have seen more benefits for their own learning performance through applying this behavior, rather than just revising their work without actively seeking criticism. It has been shown that revising one's work repeatedly, without the crucial incorporation of expert feedback into a task, does not necessarily improve performance (Ericsson, Krampe, & Tesch-Römer, 1993; Thorndike, 1927). Another possibility is that critical feedback-seeking reflects an underlying construct, such as IQ, as prior academic achievement predicts critical feedback-seeking but not with revising, after controlling for gender and the pre-test. However, a different study has found no differences in performance and learning between students who chose critical feedback and those who were assigned the same amount of critical

feedback, suggesting that the outcomes of using critical feedback are the same, regardless of other factors, such as IQ or mindset (Cutumisu, 2019).

Taken together, the results show that design-thinking choices, especially critical feedback-seeking, are the most important factors that explain the relation between prior achievement and current performance. Importantly, although prior academic achievement does not directly predict performance, not even through each of the two design-thinking choices in isolation, it indirectly predicts performance through students' combined design-thinking choices (i.e., first through critical feedback-seeking and then through revision). In prior research, it was found that mindset does not determine students' design-thinking choices (seeking critical feedback and revising their posters) or their learning outcomes (performance and learning) but it influences how students respond to their own choices (Cutumisu, 2019). Taken together, the current findings show that prior academic achievement does not inevitably determine students' performance outcomes. Instead, other factors such as mindset (which has not been measured in the current study) may shape the way students employ their design-thinking strategies to achieve a better performance.

The findings show that academic achievement is correlated with seeking critical feedback but that it is not associated with better performance when controlling for feedback choices. Indeed, academic achievement, for instance in mathematics, does not confer knowledge about digital poster design, so it is not reasonable to expect that academic achievement will predict better poster performance. For example, if the Posterlet game did not provide feedback, one would not expect high achievers to achieve better poster performance. However, this finding may challenge the views of those who think that academic achievement (e.g., a test score)

represents the sum of an individual's ability and that high achievers should be good at anything, no matter what.

These findings generalize across two different design-thinking strategies: critical feedback-seeking and revising one's work and two types of performance: prior academic achievement and current poster-design performance (and performance gain). Importantly, these learning behaviors are not tied to a certain curriculum, thus, the results are more likely to transfer to new learning environments that are abundant in design-thinking choices. Future research will focus on different demographics to ascertain whether these results generalize to other populations.

Practical Implications

As this study showed that learning behaviors such as choosing critical feedback and revising one's poster are effective behaviors for performance, practical implications include the development of learning and assessment environments that consider learning processes (e.g., choices). These design-thinking behaviors constitute important predictors and cornerstones of independent learning beyond the school environment and they can be applied to solve many different problems. More importantly, the findings of this study suggest that students need to be encouraged to seek constructive criticism and to revise, which are behaviors conducive to increased performance outcomes. They need to develop both the "skill and will" (Pintrich & De Groot, 1990) to be able to benefit the most from their learning strategies. Simply seeking critical feedback without revising one's work is a missed opportunity, as students may not take full advantage of the information gained through this type of feedback, which in turn could prevent them from improving their performance. Thus, educators may consider demonstrating these design-thinking strategies to their students, preparing them to apply these behaviors on their own

when they approach and solve new problems inside or outside their familiar school environments. This instructional goal is feasible, especially as prior research has shown that critical feedback-seeking and other so-called soft skills are amenable to interventions (Chin et al., 2019).

Conclusions

This study examined the design-thinking choices (critical feedback-seeking and revising) of sixth-grade students and found that these choices were instrumental to students' performance, even after controlling for their prior academic achievement in Mathematics, Science, and English Language Arts. Future research will investigate whether this result can be generalized to other sample sizes and demographics. Educational implications include interventions that could influence students' choices (Schwartz & Arena, 2013), nudging students towards exercising and applying these types of design-thinking behaviors (e.g., choosing critical feedback more often and revising their work frequently) to improve their performance. Thus, students will be better prepared to choose well towards better performance outcomes when they learn independently and adapt to ever-changing environments.

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Appendix A Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.compedu.2020.103806.

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Table 1

Pearson Correlations and Descriptive Statistics: Mean (M), Standard Deviation (SD), Skewness, and Kurtosis.

	2	3	4	5	6	7
1. Gender	.10	.02	-.18	**-.37****	**-.35****	.00
2. Critical Feedback-Seeking	--	**.55****	-.08	.13	.21	**.38*****
3. Revision		--	-.05	**.23***	**.30****	**.35*****
4. Pre-test			--	**.58****	.15	-.04
5. Performance				--	**.89****	-.02
6. Performance Gain					--	-.02
7. Achievement						--
Mean	4.99	1.35	8.14	32.51	24.38	0
SD	2.22	1.09	5.12	11.28	9.32	6.69
Skewness	-.26	.16	-.76	-1.00	-.30	.21
Kurtosis	-.45	-1.28	.40	2.02	1.05	.03

Notes: $^{***}p < .001$, $^{**}p < .01$, $^{*}p < .05$, two-tailed

Table 2

Model 3: Maximum Likelihood Estimates for the Final SEM Model on Performance.

Outcome variable	Predictor	*b*	*S.E.*	*t*	*p*	R^2
Critical Feedback-Seeking	Achievement	.13	.05	2.60	**.01**	**.20***
Revision						**.33***
	Critical Feedback-Seeking	.23	.05	4.20	**<.001**	
	Achievement	.03	.02	1.40	.16	
Performance						**.51***
	Critical Feedback-Seeking	.73	.52	1.39	.16	
	Achievement	-.21	.16	-1.30	.20	
	Revision	2.46	1.02	2.41	**.02**	
	Gender	-6.52	1.83	-3.56	**<.001**	
	Pre-test	1.20	.18	6.67	**<.001**	

Note: *b* = unstandardized path coefficient

Table 3

Model 4: Maximum Likelihood Estimates for the Final SEM Model on Performance Gain.

Outcome variable	Predictor	*b*	*S.E.*	*t*	*p*	R^2
Critical Feedback-Seeking	Achievement	.13	.05	2.60	**.01**	**.20***
Revision						**.33****
	Critical Feedback-Seeking	.23	.05	4.20	**<.001**	
	Achievement	.03	.02	1.40	.16	
Performance Gain						**.26****
	Critical Feedback-Seeking	.70	.53	1.34	.18	
	Achievement	-.21	.16	-1.30	.20	
	Revision	2.44	1.03	2.37	**.02**	
	Gender	-6.87	1.82	-3.78	**<.001**	

Note: *b* = unstandardized path coefficient

Figure 1. The first step of playing the Posterlet game: students design a poster by first selecting a theme for their booth from the five available themes displayed on the wheel at the right side of the screen.

Figure 2. Students can add images corresponding to each of the five possible themes on their poster.

Figure 3. Students can add text corresponding to the theme they selected for their current booth.

Figure 4. After designing their poster, students can choose three animal characters from a focus group and ask for their opinions by selecting either confirmatory or critical feedback from each of them.

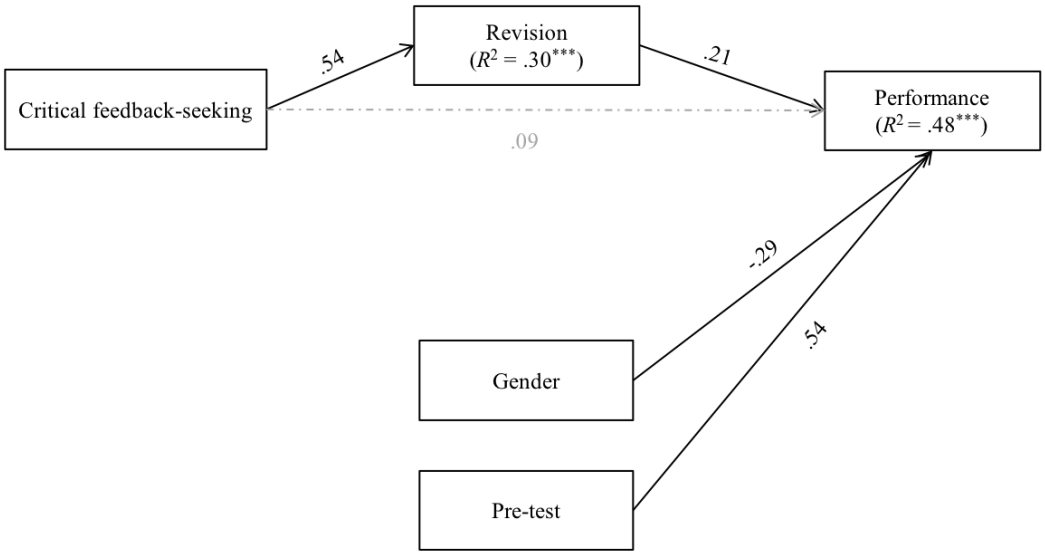

Figure 5. Model 1: revision fully mediates the link between critical feedback-seeking and performance, beyond the influence of the pre-test and gender. Thus, the effect of critical feedback-seeking on enhancing performance can be fully explained by students' choices to revise their posters.

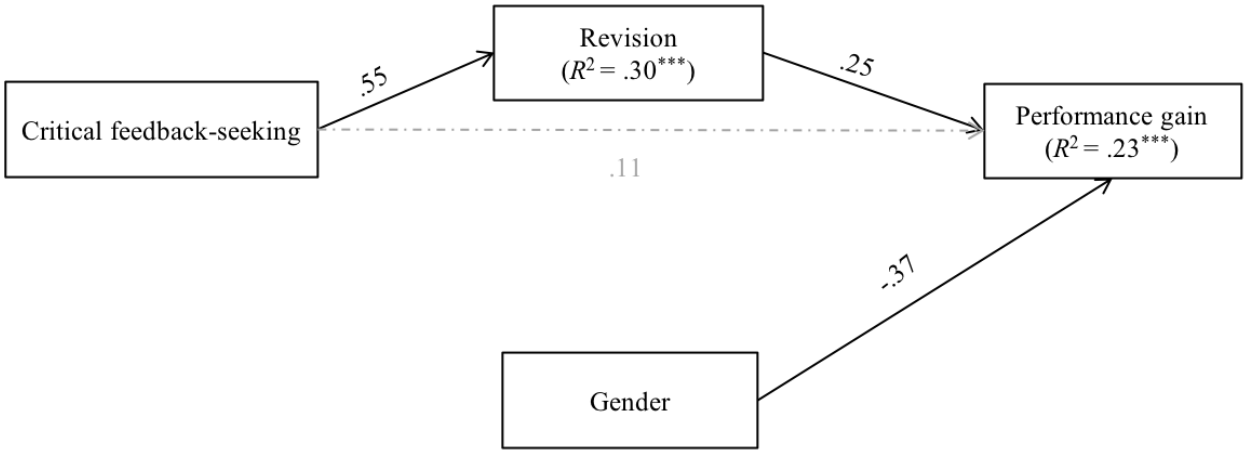

Figure 6. Model 2: revision fully mediates the link between critical feedback-seeking and performance gain after controlling for gender. Thus, the effect of critical feedback-seeking on students' gain in performance across the game is fully explained by their choice to revise their posters.

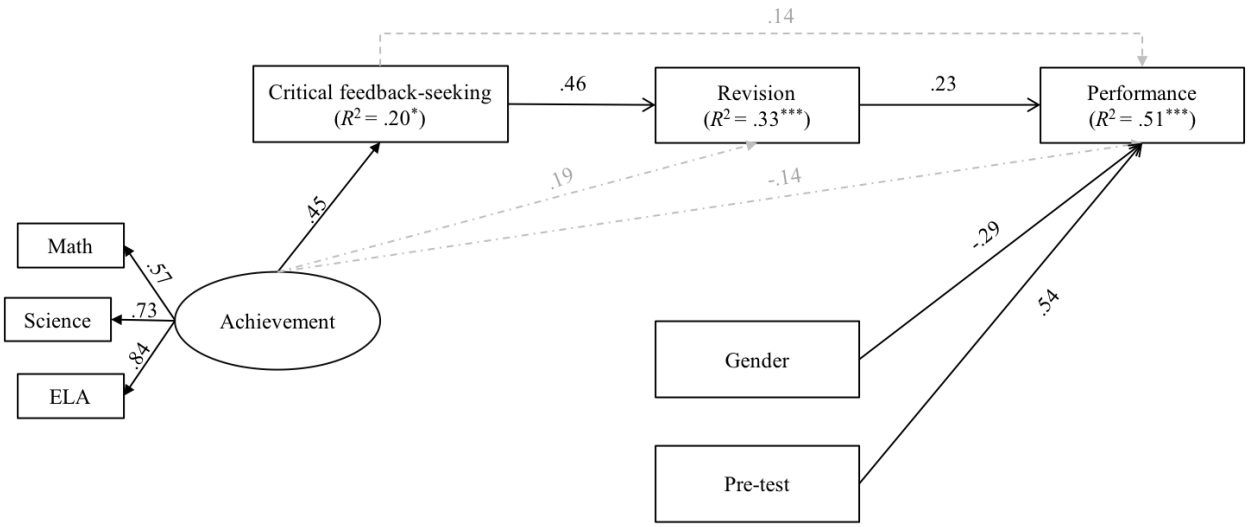

Figure 7. Model 3: revision fully mediates the relation between critical feedback-seeking and performance, beyond the influence of prior academic achievement. Achievement does not predict performance directly but it is indirectly linked to performance through feedback and revision. Although achievement was initially linked with revision, this SEM model shows that critical feedback fully mediates this link. Thus, critical feedback-seeking fully explains the link between students' prior achievement and their decision to revise their posters.

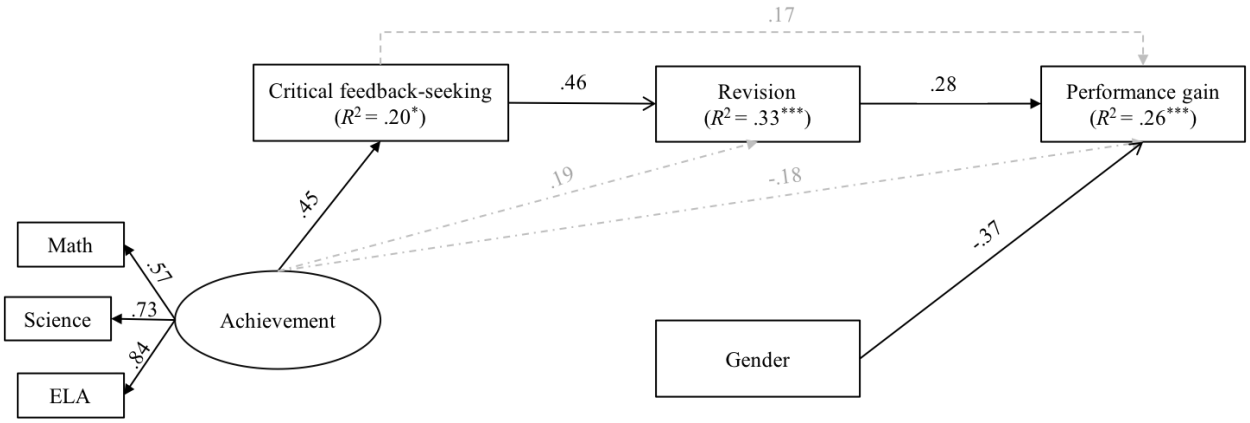

Figure 8. Model 4: revision fully mediates the link between critical feedback-seeking and performance gain, even after controlling for prior academic achievement. Achievement does not predict performance gain directly, but it predicts it indirectly, first through critical feedback-seeking and then through revision. Although achievement was initially linked with revision, this SEM model shows that critical feedback fully mediates this link.