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Abstract

In undergraduate classrooms, students are typically first taught the concepts and procedures for solving problems, then practice. With exploratory learning methods, students explore novel problems and generate original solutions before receiving instruction, which benefits conceptual understanding and future learning. The current study examined whether students who explore before instruction experience greater insight moments, and whether insight leads to better learning. Prior research demonstrates that individuals remember problem solutions better if they experience a sudden moment of solution clarity (Aha! Experience). Participants (*N* = 83) were randomly assigned to instruct-first or explore-first conditions and taught three types of magic tricks used in the insight problem solving literature. Participants in the instruct-first condition viewed the instruction and examples, then practiced solving the problems. Participants in the explore-first condition explored the problems and provided solution attempts before instruction. After one week, participants were asked to recall solutions from the prior week. They also provided solutions to six new tricks, which assess near and far transfer differing by how similar the solutions were to the previous problems. Participants in both conditions scored equally on recall and near transfer problems, but participants in the explore-first condition scored higher on far transfer problems. Insight ratings did not differ between conditions. Insight ratings did not correlate with memory for solutions, but a related affective experience (certainty) did. These findings suggest that the insight memory advantage was not specific to exploratory learning, but exploring before instruction improved understanding of the deeper concepts.

Keywords: Exploratory Learning, Insight, Conceptual Understanding, Magic Tricks

Aha! Examining Insight In Exploratory Learning Versus Traditional Instruction

Instructors in the U.S. generally teach students formulas or solution methods prior to providing practice problems. Students traditionally learn that there is one or few ways to solve a particular type of problem and may not spend time exploring problems to generate original ideas (DeCaro, 2016). This type of rote memorization and teaching may not be conducive to insightful learning, in which one has a sudden realization stemming from individual thought. Giving students the opportunity to explore and figure out problems on their own may promote greater interest in learning, increase insight-based solutions, and boost long-term memory. Enhancing these processes potentially has great implications for education in the U.S. today, which could benefit from research-supported, active learning methods.

Research on *exploratory learning* compares traditional instruct-then-practice teaching methods to explore-first methods. In instruct-then-practice methods, students are taught about a new topic prior to solving relevant problems. In explore-first methods, students engage with material and attempt solutions on their own prior to instruction. Exploratory learning is thought to benefit students' conceptual knowledge through several cognitive mechanisms: activation of prior knowledge, awareness of knowledge gaps, and discernment of problem features (Loibl et al., 2016). By exploring, students become aware of past-learned concepts that may help them with the current problem. This process raises questions about what problem parts they do not know and helps them recognize deeper problem features that may be applicable to previous and future concepts. Engaging students in active, connected thought allows them to spend more time *understanding* their work, which improves memory compared to being passively taught solutions.

Exploratory learning studies also differ in the type of activity or instruction given to students. Some ask students to "invent" one solution, such as an index (Schwartz & Martin, 2004). Others ask students to "generate" as many solution attempts as possible (Loibl et al., 2020). These prompts come from the "productive failure" literature, which shows that the problem-solving phase before direct instruction benefits conceptual understanding (Kapur, 2012). Generating multiple strategies sometimes seems to have greater learning benefits than instructions to invent a single solution, but more research is needed in this area. This benefit may be due to the activation of divergent reasoning processes, which encourages greater spread of mental search and representation as well as greater cognitive "flexibility," as described in research on mental processes involved in creativity (Zhang, Sjoerds, & Hommel, 2020).

Research by Zhang et al. (2020) also points to an association between divergent thinking and insight solutions, parallel to a link between convergent thinking processes and more analytic reasoning-based solutions. Thus, there may exist a connection between benefits of exploratory learning and those of another field of literature, that of the *insight memory advantage*. Research on the insight memory advantage posits that experiencing insight (often characterized by "Aha! moments") while solving problems improves solution memory (Danek & Wiley, 2020). As described by Liljedahl (2005), a moment of insight occurs when, "suddenly, it's all illuminated" (p. 219). This moment of all-at-once problem solving often occurs after effortful cognitive processes have already been devoted to working with problem features and solution-searching (Liljedahl, 2005). Often, we may feel that we have made no progress when the answer seems to appear in our mind. This moment of insight may later make us feel that we can more easily and better remember the suddenly found solution than solutions for which we did not have this experience.

Pathways to The Insight Memory Advantage

Insight research tends to focus on two pathways that potentially modulate this advantage for long-term memory, as summarized by Danek & Wiley (2020). Some studies investigate a cognitive pathway, focusing on the representational change that occurs during insight problem solving (e.g., Ash & Wiley, 2008). Such research emphasizes the overcoming of cognitive conflict, or the process by which an initially incorrect mental representation of a problem must be both recognized and corrected in order for participants to successfully solve the problem (Danek & Flanagin, 2019).

Other insight research focuses instead on a pathway including the affective component of insight. Such research posits that those solutions to problems for which solvers report feeling an "Aha!" experience for correct, self-generated solutions are remembered better than those for which they were *shown* the correct solution or which did not involve an Aha! moment (Danek et al., 2012; Danek & Wiley, 2020; Dominowski & Buyer, 2000). The Aha! experience is a complex, "multi-dimensional construct" that is described as involving positive emotions such as pleasure, certainty, confidence in solution attempts, and suddenness at the moment of insight (Auble et al., 1979; Kizilirmak et al., 2015; Pétervári & Danek, 2019; Topolinski & Reber, 2010).

Indeed, Danek and Wiley (2020) demonstrate that it is positive feeling that drives the memory advantage. Liljedahl (2005) demonstrated that the subjective Aha! moment often follows long, effortful thinking and problem-solving attempts in mathematics classrooms. This breakthrough contributes to the relief and feelings of pleasure associated with the moment of insight. Liljedahl further demonstrated the significance of positive affect; not only did a personal Aha! experience improve transient emotions, but it also often caused more long-term, influential changes in students' beliefs and attitudes toward mathematics and their own capabilities. However, some studies have pointed out that insight problem-solving can occur absent the Aha! experience (Danek & Flanagin, 2019).

Many underlying processes appear to be involved in both exploratory learning and insight learning. Curiosity, for example, has been associated with increasing motivation to fill knowledge gaps and therefore improving learning (Lamnina & Chase, 2019). Lamnina & Chase further describe the promotion of curiosity by feelings of uncertainty, which relate to the processes that occur during a student's exploratory phase of problem solving. Although research on both exploratory learning and insight memory emphasize the role of positive emotions in boosting memory, some exploratory learning studies have shown that certain "negative" emotions (e.g., "self-conscious" and "hostile" emotions) may improve memory as well (Sinha, 2021). Thus, these emotions were investigated in our study as well.

Current Study

This study connects the exploratory learning and insight problem solving literatures, specifically examining the extent to which (a) insight is experienced during exploratory learning, and (b) insight is connected to conceptual learning outcomes. Several investigations into the cognitive and affective components of insight have used magic tricks to assess participants' problem-solving performance (Danek & Flanagin, 2019; Danek & Wiley, 2020; Pétervári & Danek, 2019). This study adapted these materials using magic tricks and their solutions to compare two learning conditions tested in exploratory learning literature. Participants in the *instruct-first condition* were taught three concepts, with solutions using six magic trick problems as examples. Then they practiced applying these solutions to the same problems they viewed as instruction, similar to a traditional instruct-then-practice format in a classroom. Participants in the *explore-first condition* saw the magic tricks first, trying to solve them on their own prior to learning the solutions and underlying concepts. A week later, all participants were asked to recall the trick solutions and solve (try to figure out the solutions for) six new, but related, magic trick problems (i.e., transfer; Gick & Holyoak, 1983). These conditions are similar to insight memory study conditions in which participants are asked to generate their own solutions or are simply told the correct solutions prior to a subsequent memory test. Dominowski and Buyer (2000), for example, tested recall after one week and found almost perfect memory in the generate condition compared to the told-solution condition. However, this advantage was specific to generating a *correct* solution.

The present study differed from Danek and Wiley's study (2020) in several ways. As Danek and Wiley sought to replicate the insight memory advantage and investigate the relative importance of cognitive and affective components, a controlled told-solution condition (e.g., the instruct-first condition in the present study) was not included. Therefore, Danek and Wiley did not include a measure of Aha! or certainty ratings in Experiment 1 for "shown solution" trials. This study added these in the instruct-first condition, in order to compare measures of positive affect components of the Aha! experience with the explore-first (generate) condition. Additionally, this study instructed on concepts underlying the problem-solving items (magic tricks), as grouped based on their essential principles. These principles were determined based on similar characteristics or methods of trick strategies. The goal was to help participants generalize the principles (concepts), so that they might transfer their understanding of these concepts to new, related problems, as in other exploratory learning studies (e.g., Schwartz & Martin, 2004). To test this possibility, this study added transfer measures (Barnett & Ceci, 2002; Gick &

Holyoak, 1983) in order to assess possible benefits in the explore-first condition to solve problems in related categories or that share deep problem features.

Compared to participants in the explore-first condition, we predicted that participants in the instruct-first condition would score higher on correctness of solution attempts, as they were taught the solutions prior to problem solving and were therefore expected to have higher procedural fluency (Loibl et al., 2020). We hypothesized that participants in both conditions would score equally on correctness of solution recall attempts. Prior research on exploratory learning has demonstrated that the benefits of exploring are selective to assessments of conceptual understanding and transfer, but not to mastery of rote procedures or facts (Loibl et al., 2016). In addition, the insight literature suggests that participants better remember solutions to problems they are shown at a relatively high level, as long as they experienced an Aha! moment (Danek & Wiley, 2020). We also predicted that participants in the explore-first condition would score higher on the transfer measures, suggesting benefits to conceptual understanding as a result of generating problem answers for oneself before instruction on the solutions and underlying concepts (Schwartz & Martin, 2004). We predicted that participants in the explore first condition would report higher positive affect (i.e., pleasure, relief, and suddenness) and certainty ratings (comprising the Aha! experience), which would suggest more moments of insight problem solving through strategy generation compared to participants in the instruct-first condition. Finally, we predicted that correctness, recall, and transfer scores would be correlated with these key components of the Aha! experience. Danek and Wiley (2020) found that Aha! ratings were correlated with correctness and recall, but did not include transfer in their investigation. We hypothesized that the positive correlation would be extended to include transfer, due to the exploratory learning setting. If the former hypotheses were supported, it would suggest that the affective components of insight are associated with the exploratory learning memory advantage as well.

Methods

Participants

Participants were undergraduate students (N = 83, 74.7% female, M_{age} = 19.28 years, SD = 1.33) from the psychology participant pool who completed both sessions of the study. Participants received course credit for the first session, and course credit or a $5 gift card for completing the second session. Ten additional participants were excluded for marking on the *prior knowledge* items that they knew “quite a bit” (4) or “very much” (5) about the solutions to the magic tricks before the study. Three additional participants were excluded for (a) using their phone during solutions, (b) skipping several survey items, and (c) because an alarm went off during their session.

Materials

Instruction and Problem Solving

All participants completed both instruction and problem-solving sections, with the order varying by condition. In the *instruction section,* participants read about three types of deception used in magic tricks. This instruction included an overview of three common deception methods used by magicians categorized as “shell,” “invisible hole,” and “hidden movement” (see Table 1). Then, participants viewed two example tricks from each of these trick type categories, with solutions (for a total of six solution clips). Solution videos were labeled under their trick category and were captioned with a written explanation of the solution. Solution clips ranged from 12 to 26 seconds.

In the *problem-solving section,* participants viewed the same magic tricks as in the instruction, except these videoclips showed the tricks as they would be performed to an audience. The 6 videos in this section ranged from 9 to 23 seconds. Participants were asked to provide a solution attempt following each video. In the *instruct-first* condition, participants were asked, “What idea(s) do you remember that might explain how the magician performed the trick?” In the *explore-first* condition, participants were asked, “What idea(s) do you have that might explain how the magician performed the trick?”

Participants were allowed three minutes to explore each video. They were allowed to press pause, rewind, and rewatch the videos. Videoclips used in this study were provided in collaboration with Dr. Amory Danek and performed by magician Thomas Fraps (Danek & Wiley, 2020).

Table 1

Deception Categories and Description of Tricks

Trick Category	Description of Tricks	Description of Transfer
“Shell”	Fake “half” coin conceals whole coin.	“Half” orange conceals whole apple. (near)
	Fake “half” of one red ball conceals whole ball.	A fake spoon covers the fork prongs. (far)
“Invisible Hole”	Scarf is concealed in a hidden hole in the egg held in magician’s fist.	Bowling ball is pushed all the way through a hidden hole in the suitcase. (near)
	Hanger is pulled through purse hole from magician’s sleeve.	Magician uses two ropes but hides the cut ends with his hand. (far)
“Hidden Movement”	Drops glass, the scarf fully concealing the practiced movement.	Magician quickly turns the glass 180 degrees behind the scarf. (near)
	Drops cigarette and lighter while drawing away attention.	Magician discreetly slides the coin under the napkin with one finger. (far)

Affect Ratings and Solution Prompt

After each video (during instruction and problem solving), participants responded to affect items on a 5-point Likert scale indicating the extent they felt each emotion (1 = *not at all*, 2 = *slightly*, 3 = *moderately*, 4 = *quite a bit*, 5 = *very much*). Affect ratings included measures of an *Aha! moment*, *suddenness*, *certainty*, *pleasure*, *anger*, *curiosity*, *surprise*, *confusion*, *relief*, *shame*, *confidence*, and *interest* (Danek & Wiley, 2020; Sinha, 2021). For example, participants responded to the statements, "The solution came to me suddenly" and "I am certain my solution is correct." They also responded to affect statements including "I felt pleasure" and "I felt relief." In the problem-solving section only, participants were prompted to provide solutions before they provided affect ratings. The solution prompts followed by a large textbox appeared immediately after each video. Instructions were given to participants, regardless of condition, to only provide "plausible" solution attempts, rather than magical phenomena as trick explanation (Danek & Wiley, 2020).

Learning Survey

After both the instruction and problem-solving sections, participants were asked to respond to a learning survey given on a 5-point Likert scale (1 = *strongly disagree* to 5 = *strongly agree)*. The survey consisted of 23 statements assessing participants' experiences as *situational interest* (3 items; Rotgans & Schmidt, 2014; e.g., "I enjoyed working on this activity"), *perceived knowledge gaps* (4 items; Flynn & Goldsmith, 1999; e.g., "I do not feel very knowledgeable about this topic"), *curiosity* (6 items; Naylor, F. D., 1981; "I feel like searching for answers"), *self-efficacy* (2 items; Findley-Van Nostrand & Pollenz, 2017; "I feel confident in my ability to learn this topic"), *competence* (2 items; Sheldon et al., 2001; "Thanks to today's learning activities, I feel more competent in this topic area"), and *flow* (6 items; Rheinberg, Vollmeyer, & Engeser, 2003; e.g., “I feel that I have everything under control”). After answering these questions, participants also responded to a cognitive load item (1 item; Paas, 1992; i.e., “Please indicate how much mental effort you invested when working on the previous activity”) on a 9-point scale (1 = *very, very low mental effort*; 9 = *very, very high mental effort*).

At the end of the session and the second learning survey, participants also answered questions assessing their *prior knowledge* of the included tricks, their understanding of what is meant by an Aha! moment, and demographics.

Figure 1

Example Screenshots of “Invisible Hole” Trick, Shown in Second Session

Recall and Transfer Assessment

To assess solution recall and long-term learning, participants completed a second session approximately one week after their first session. Participants first viewed two screenshots from each trick from the prior week (see Figure 1) and were instructed to “remember the solutions you gave to the same tricks you saw last week” (*Recall* items). Then, participants completed *transfer* items, solving new but related problems (Gick & Holyoak, 1983). For each original trick type, two new tricks were shown that used a slightly different but related solution method (for a total of six new tricks). One of these new tricks was more related to the original category (*near transfer*) while one was less related (*far transfer*) (See Table 1). Transfer clip videos ranged from 9 to 21 seconds. After viewing each video, participants were asked, “What idea(s) do you have that might explain how the magician performed the trick?”

Participants answered self-report items related to their level of exploration over the course of the study. These items asked about how often participants rewound, paused, or rewatched the videoclips. These items were not analyzed in the current study.

Procedure

Participants completed the instruction, problem solving, and surveys in individual lab sessions on a computer. Participants were randomly assigned to condition. After providing informed consent, participants in the *instruct-first* condition viewed the instruction, then the problem-solving task. Participants in the *explore-first* condition completed the problem-solving task followed by the instruction. After each problem, participants responded to the affect and solution prompts.

Approximately one week after the first session, participants completed the recall and transfer tests online. An email was sent to participants on the fifth, seventh, and ninth days after completion of the first session, or until they had completed the second survey. A link to the second survey was provided in the email. At the end of the online session, they viewed a written debriefing statement and were invited to contact the researcher with any questions.

Coding

Problem solutions were scored using a coding manual established by Danek and Wiley (2020) in collaboration with the magician. Solution and transfer correctness were scored as correct (including "plausible alternative solutions") or incorrect (including "partial" and "implausible" solutions). Recall attempts were scored as recalled or not recalled, based on whether participants answered with the taught solution from the first week (i.e., participants did not have to get the solution right in the first session to recall it correctly). One coder scored solution correctness, recall, and transfer responses using the same procedure used by Danek and Wiley (2020). A second coder will rescore 20-100% for inter-rater reliability.

Results

Correctness Scores

The number of magic trick problems that participants solved correctly (out of six) in the first week of the study were averaged and entered into an ANOVA as a function of exploratory learning condition. The overall effect of condition on solution correctness across these items was significant (instruct-first condition: M = 5.70 out of 6, SD = 0.62; explore-first condition: M = 3.46, SD = 1.13), $F(1, 81) = 117.80$, $p < .001$, indicating that correctness differed between conditions. Participants in the instruct-first condition were more accurate on the problems overall (see Figure 2).

Recall Scores

Comparing recall scores in the second week of the study revealed no difference between conditions (instruct-first condition: M = 5.49 out of 6, SD = 0.90; explore-first condition: M = 5.20, SD = 1.19), $F(1,81) = 1.52$, $p = .221$. Participants in both groups scored similarly highly on recall items (see Figure 2).

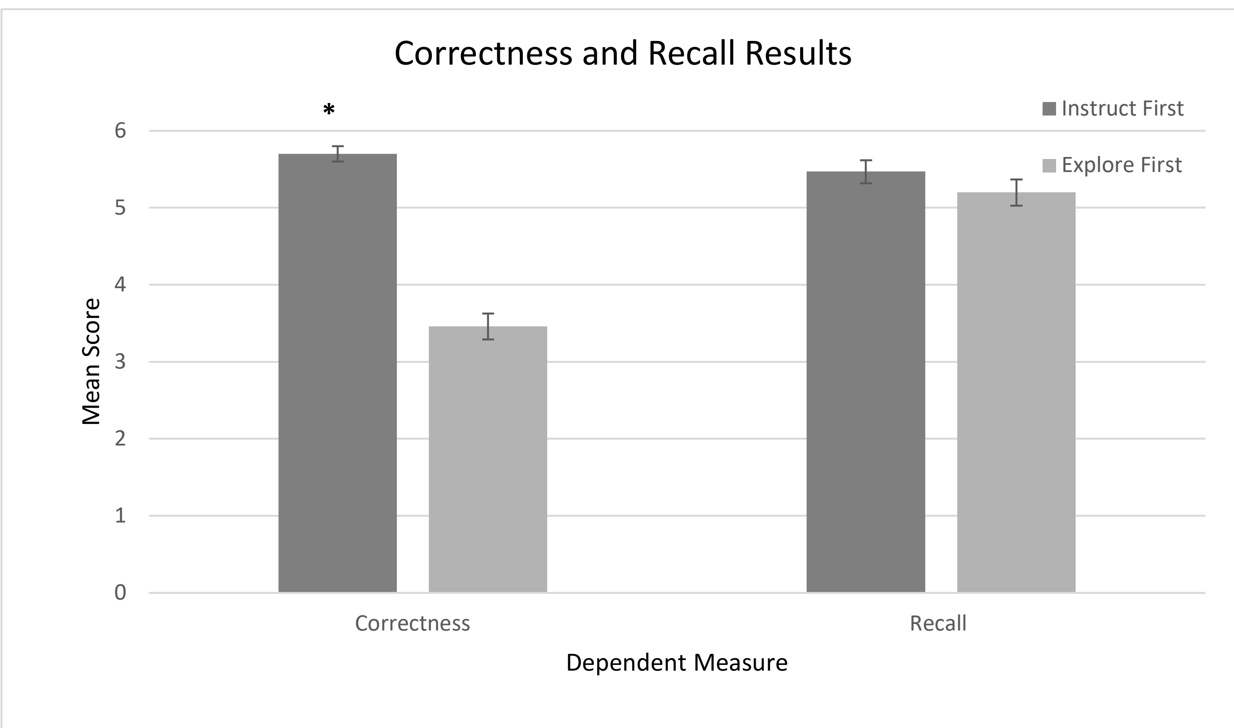
Transfer Scores

Transfer scores were divided into near and far transfer score subscales for analysis. Comparing near transfer scores (magic tricks more closely related to the original trick category) between conditions revealed no significant difference (instruct-first condition: *M* = 1.11 out of 3, *SD* = 0.91; explore-first condition: *M* = 0.93, *SD* = .83), $F < 1$, $p = .336$. However, comparing far transfer (magic tricks less closely related to the original category) revealed that participants in the explore-first condition (*M* = 1.26, *SD* = 0.91) scored higher than those in the instruct-first condition (*M* = 0.87, *SD* = 0.86), $F(1,81) = 4.12$, $p = .046$ (see Figure 3).

Correctness was positively correlated with recall, $r(81) = .27$, $p = .014$. There was no correlation between correctness and transfer, $r(81) = .07$, $p = .56$, nor between recall and transfer, $r(81) = .20$, $p = .07$.

Figure 2

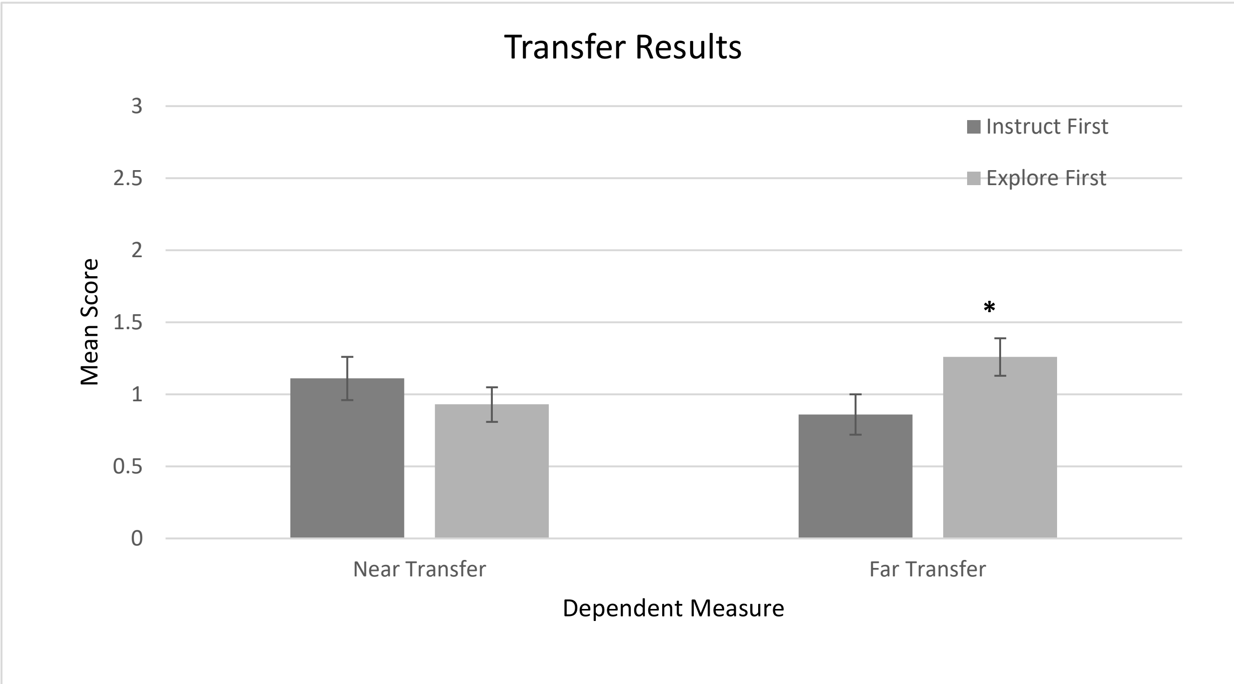
Mean Scores on Correctness and Recall Measures Between Conditions



Note. Error bars represent standard errors.

Figure 3

Mean Scores on Near and Far Transfer Measures Between Conditions



Note. Error bars represent standard errors.

Survey Items

No effects of condition were found on any of the survey variables, *F*s = .00 to 3.73, *p*s = .994 to .057, except for *relief* ratings after the problem solving section, $F(1, 81) = 5.35$, $p = .023$ (see Table 2). Participants in the instruct-first condition reported higher relief ratings.

Averages for Correctness, Recall, and Transfer scores were used to examine correlations with key survey variables, in order to demonstrate whether participants showed a memory advantage related to greater insight or associated affect. *Aha!* ratings were not correlated with Correctness, Recall, or Transfer, *r*s = -.01 to .11, *p*s = .92 to .06. *Pleasure* also showed no significant correlations between the averaged scores, *r*s = -.21 to .37, *p*s = .63 to .06. *Certainty* during problem solving was positively correlated with recall, $r(81) = .29$, $p = .009$.

Aha! Experience

Aha! ratings were analyzed for correlation with any other survey items, in order to examine whether the study replicated the Aha! experience, described in Danek & Wiley (2020). In the problem-solving section, *Aha!* was significantly correlated with *suddenness,* $r(81) = .26$, $p = .020$; *pleasure,* $r(81) = .61$, $p < .001$; *curiosity,* $r(81) = .33$, $p = .002$; *surprise,* $r(81) = .29$, $p = .007$; *relief,* $r(81) = .36$, $p < .001$; and *confidence,* $r(81) = .27$, $p = .013$. *Aha!* ratings were not correlated with the other survey measures (*r*s = .05 to .19, *p*s = .68 to .09). In the instruction section, *Aha!* was significantly correlated with *suddenness,* $r(81) = .67$, $p < .001$; *pleasure,* $r(81) = .52$, $p < .001$; *relief,* $r(81) = .53$, $p < .001$; *shame,* $r(81) = .29$, $p = .009$; and *confidence,* $r(81) = .55$, $p < 001$. *Aha!* ratings were not correlated with the other survey measures (*r*s = -.16 to .17, *p*s = .20 to .12). Thus, these results suggest that the Aha! experience was replicated in this study with key measures of pleasure and suddenness.

Table 2

Means, Standard Errors, and Confidence Intervals For Survey Data as a Function of Condition

Item	Instruct-First			Explore-First		
	M	*SD*	95% CI	M	SD	95% CI
			Instruction Section, Affect Ratings			
Aha!	3.12	.94	[3.11, 3.73]	3.44	.92	[3.17, 3.71]
Suddenness	3.23	.96	[2.91, 3.55]	3.28	1.05	[2.97, 3.59]
Pleasure	3.23	1.17	[2.84, 3.62]	3.23	1.27	[2.86, 3.61]
Anger	1.34	.74	[1.09, 1.59]	1.56	.26	[1.08, 1.23]
Curiosity	2.97	.93	[2.66, 3.28]	3.09	1.00	[2.80, 3.39]
Surprise	2.76	.87	[2.47, 3.05]	2.67	.79	[2.44, 2.91]
Confusion	2.00	.99	[1.67, 2.33]	1.74	.78	[1.50, 1.97]
Relief	2.65	1.27	[2.23,3.08]	2.53	1.26	[2.16, 2.91]
Shame	1.37	.78	[1.11, 1.63]	1.12	.35	[1.01, 1.22]
Confidence	2.60	1.31	[2.16, 3.03]	2.86	1.22	[2.50, 3.22]

			Problem Solving, Affect Ratings			
Aha!	2.73	1.07	[2.37, 3.08]	2.83	1.02	[2.53, 3.13]
Suddenness	3.28	1.01	[2.95, 3.62]	3.18	1.14	[2.84, 3.52]
Certainty	3.66	1.18	[3.60, 4.05]	3.34	1.18	[2.99, 3.70]
Pleasure	2.73	1.00	[2.40, 3.07]	2.57	1.09	[2.25, 2.90]
Anger	1.23	.42	[1.09, 1.37]	1.27	.38	[1.16, 1.38]
Curiosity	2.85	1.02	[2.51, 3.19]	3.11	1.17	[2.76, 3.46]
Surprise	2.31	.88	[2.01, 2.60]	2.35	.99	[2.06, 2.64]
Confusion	2.15	.91	[1.85, 2.46]	2.38	.98	[2.09, 2.67]
Relief *	2.12	.84	[1.84, 2.40]	1.72	.74	[1.50, 1.94]
Shame	1.15	.38	[1.03, 1.28]	1.06	.19	[1.01, 1.12]
Confidence	3.02	1.07	[2.66, 3.38]	2.89	1.15	[2.55, 3.23]
			Instruction Section, Learning Survey			
Interest	3.33	.97	[3.01, 3.65]	6.08	1.02	[3.04, 3.65]
Sit. Interest	4.19	.55	[4.00, 4.37]	3.34	.52	[4.12, 4.43]
Knowl. Gaps	3.23	.67	[3.01, 3.45]	4.28	.70	[3.01, 3.45]
Curiosity	3.78	.56	[3.59, 3.97]	3.08	.57	[3.58, 3.92]
Flow	3.94	.48	[3.78, 4.10]	3.75	.50	[3.85, 4.15]
Self-Efficacy	4.15	.45	[4.00, 4.30]	4.00	.54	[4.06, 4.38]
Competence	3.91	.63	[3.69, 4.11]	4.22	.63	[3.77, 4.14]
Cogn. Load	6.08	1.72	[5.51, 6.66]	3.96	2.01	[5.53, 6.73]
			Problem Solving, Learning Survey			
Interest	3.34	1.09	[2.98, 3.70]	3.24	.68	[3.02, 3.47]
Sit. Interest	4.19	.57	[4.00, 4.38]	4.19	.64	[3.67, 4.09]
Knowl. Gaps	3.24	.68	[3.02, 3.47]	3.36	.41	[3.72, 4.00]
Curiosity	3.88	.64	[3.67, 4.09]	3.84	.55	[3.88, 4.25]
Flow	3.86	.41	[3.72, 4.00]	3.87	.62	[3.61, 4.02]
Self-Efficacy	4.07	.55	[3.88, 4.25]	4.00	1.63	[5.89, 6.97]
Competence	3.81	.62	[3.61, 4.02]	3.60	1.16	[2.90, 3.59]
Cogn. Load	6.43	1.63	[5.89, 6.97]	3.67	.54	[4.03, 4.35]

*Significantly different as a function of condition ($p<.05$)

Discussion

The purpose of this study was to examine the occurrence of insight during exploratory learning and the potential effects of insight on conceptual learning outcomes. Some participants were taught magic trick solutions prior to practicing, whereas others first tried to figure out the tricks on their own. All participants completed memory and transfer assessments to examine the extent to which these outcomes differed between conditions.

Problem Solving Correctness, Recall, and Transfer

Correctness, recall, and transfer scores generally supported the hypotheses for this study when compared between the two conditions. Participants in the explore-first condition scored significantly lower on solution correctness, replicating findings from the exploratory learning research literature (Loibl et al., 2020). This finding demonstrates that those who are asked to generate solutions for themselves, before instruction, experience greater difficulty than those who simply solve problems as practice after instruction (Kapur, 2012).

Recall scores, which reflect procedural rather than conceptual knowledge, did not differ between conditions, in line with previous exploratory learning literature (Loibl et al., 2016). This finding indicates that whether participants explored before or after instruction, there was no advantage or disadvantage in regard to recalling the correct solutions, likely because all participants were given the answer.

When participants completed items that measure transfer, scores in both conditions were relatively low, about one correct out of three. These results may be due to the difficult nature of the magic tricks themselves, which is indicated by the lower scores on correctness of explore-first participants in Week 1. Also, participants were not informed that transfer trick solutions fell into the original trick categories. This component may have added to the challenge of solving problems not so clearly related to the learned tricks (Gick & Holyoak, 1983).

However, transfer score results differed based on the type of transfer being analyzed. Participants in the explore-first condition and instruct-first conditions scored equally on near transfer a week after learning solutions to the first set of tricks. However, students in the explore-first condition scored higher on the far transfer problems. Far transfer tricks were less closely related to the original trick categories than near transfer tricks. These results replicate previous findings in exploratory learning literature, showing that exploration prior to instruction generally improves conceptual knowledge and transfer, though not the basic facts or procedures taught during instruction (Loibl et al., 2016).

Perhaps the most compelling of the findings comparing problem solving between conditions is that exploring magic tricks in the first week (prior to any instruction) was associated with higher levels of correctness a week later on tricks less closely related to the original categories. This advantage of exploring shows the reach of the effect. This finding also occurred despite the lower correctness shown in the explore-first condition in the first week, on the problems they were asked to explore. The explore-first condition's memory of the solutions to these same problems rose to the level of the instruct-first condition one week later. These findings are consistent with the idea that exploring provides productive failure—despite greater challenge during learning, this challenge is beneficial for deeper understanding (Kapur, 2012).

Insight Memory Advantage

Correctness in week one of the study was positively correlated with recall across both conditions. Although not reported in this manuscript, preliminary analyses demonstrated that this effect occurred for both the instruct-first and explore-first conditions, even though students in the instruct-first condition were taught the correct solutions. This finding reflects Danek and Wiley's (2020) in that, by correctly providing the solution to the magic tricks, participants were likely to recall those same correct solutions later.

The study replicated many important components of the Aha! experience, both during problem solving and instruction. During both learning about the correct solutions to the magic tricks and practicing applying the correct solution to problems, a feeling of Aha! was correlated with pleasure, suddenness, relief, and confidence. Pleasure, suddenness, and relief were three out of six of the main scales comprising the experience that were examined in Danek & Wiley (2020). Thus, significant findings for these components were replicated in our study, providing support in the context of an exploratory learning study. This replication reveals that exploration should not impact the quality or scope of the Aha! experience.

Interestingly, the affective measure for shame was correlated with Aha! ratings during the instruction section, when all participants were provided the correct solutions to the magic tricks shown. Sinha (2021) investigated shame in a study examining facial expressions and affective states during problem solving-before-instruction conditions, finding higher levels of shame in the conditions compared to traditional instruction. Sinha proposed that shame may function as a "motivator for sensemaking" in certain settings. Though in the current study there were no differences between conditions for experiences of shame, shame was significantly correlated with the Aha! Experience across conditions. This finding may open a line of research to investigate other emotions, specifically negative ones, and how they may play a role in the Aha! experience of insight.

None of the measures of correctness, recall, or transfer were correlated with any of the survey items, whereas Danek and Wiley (2020; Exp. 2) found that Aha! experiences were correlated with correctness and recall. Danek and Wiley (2020), however, assessed these relationships in a different way, by including the correlations between each individual problem's accuracy and the corresponding affect ratings. Given time limitations, we averaged across all problems, thus reducing our power. Further analyses using Danek and Wiley's method might show similar results, and are planned for the future.

The only survey item found to be affected by condition was relief, with participants who received instruction first reporting higher relief than those exploring first during the problem-solving section. These results did not support the hypothesis that the explore-first condition would experience higher affect ratings on items comprising the Aha! experience, such as pleasure.

Limitations

One limitation that could have affected the results are notable ceiling effects. For example, particularly for the recall assessment in week two of the study, the mean scores in both conditions were relatively high. Students who participated in both weeks may have been motivated and interested enough in the topic that they remembered well, regardless of condition. Additionally, the wording of the recall task could have posed a potential limitation. The task was worded similarly to that used by Danek and Wiley (2020); participants were instructed to "remember the solutions you gave to the same tricks you saw last week." However, participants in the explore-first condition were not less likely to write the correct solution from Week 1 than instruct-first, despite showing lower accuracy in Week 1. This finding suggests that participants recalled the solution they were taught, rather than the solution they used. However, it is possible that the instructions led to underreporting of the correct solution from Week 1.

Another broader limitation regarding the generalization of the study is that the magic trick stimuli were likely more interesting than many topics students are instructed on in school. Participants in both conditions commented on the study being fun or interesting, and situational interest ratings averaged around 4 on a 5-point scale. However, instruction on groups or categories of tricks was provided to emulate the structure of more traditional lessons, such as math teachers providing a formula that can be used to solve a particular type of problem. Future studies may use traditional subject materials in a similar design.

Related to the categories used in the study (i.e., *shell*, *invisible hole*, and *hidden movement*), another limitation could be the selection of the tricks in the study design process. Six tricks were chosen from a selection of 37 tricks, 18 of which were used in Danek & Wiley (2020). Using different tricks or different categories based on specific problem features may yield different results.

Conclusion

Perhaps the most compelling of the study's findings is that participants who explored the magic tricks in the first week, prior to any instruction, demonstrated greater knowledge on far transfer items that were less related to the instructed solution categories. Several aspects of the Aha! Experience were replicated, and a new emotion (i.e., shame) was also shown to be related to the Aha! Experience in the context of exploratory learning. Further work should replicate the analyses used by Danek and Wiley (2020) to parse out potential associations among affective measures, which would further connect the two literatures and contribute to research on motivation, affect, and insight during learning. Future studies may also use less intrinsically interesting subject material, in order to control for high levels of positive affect or interest across conditions.

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