Focus Article

The role of guidance in children's discovery learning

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Discovery learning is an important, yet controversial topic in the fields of psychology, education, and cognitive science. Though traditional views emphasize a lack of instructional constraint or scaffolding, more recent evidence suggests that guidance should be included in the process of discovery learning. The present review summarizes three general approaches which have been shown to facilitate guided discovery learning: (1) strategic presentation of materials, (2) consequential feedback, and (3) probing questions and self-explanations. Techniques for implementing approaches are discussed, as well as the underlying mechanisms that contribute to their effectiveness.

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INTRODUCTION

Learning by discovery is a technique for helping learners create and organize knowledge. Involving mindful participation and active inquiry, it typically takes place during problem-solving situations. The learner draws upon past knowledge and experience to infer underlying strategies and gain an understanding of concepts. Traditional theories of learning suggest that discovery plays an important role in learning about abstract concepts[1] and in increasing student persistence and creativity.[2] More recent theories have also emphasized the view of the child as an active participant, as opposed to a passive recipient, in the learning process. For example, *theory* posits that young children learn in a process akin to the scientific method: examining current experience in the face of prior beliefs or theories. Young children seek out underlying causes to phenomena[3] and can become curious in the face of confusing or anomalous data.[4] The resulting perspective is of a child who can benefit and learn via discovery.

In short, discovery learning is a long-standing tradition that spans areas of psychology, education, and cognitive science. Furthermore, decades of research provide some support for discovery learning as a beneficial approach. Still, a significant question remains within discovery learning processes: shall the educator guide the learning process or should the child be allowed to pursue his/her interests without constraint? Mayer[5] suggested that discovery learning should not be considered a single pedagogical practice, but rather a range. He made the distinction between *pure discovery* and *guided discovery*, with the former referring to learning without constraint or intervention by the instructor. The latter is similar to the Vygotskian concept of *scaffolding*[6]: guidance that is dynamic and responsive to the learner's current state of experience and ability, with inexperienced learners receiving greater guidance or supervision and experienced learners receiving less intervention. Furthermore, Mayer differentiated types of activity during learning: behavioral and cognitive. In his view, pure discovery methods, with an emphasis on hands-on engagement and unfettered exploration, typically lead to behavioral activity. However, this type of involvement may not spark a commensurate level of cognitive activity, where the learner is effectively challenged to organize/reorganize knowledge, consider different strategies or perspectives, and make metacognitive assessments. Mayer suggests that it is this type of activity that discovery-based practices should strive to facilitate.

Chi[7] proposed a similar taxonomy of learning engagement. She differentiates active, constructive, and interactive activities. Active refers to an overt, physical function, such as manipulating an object or underlining a portion of a text. Similar to Mayer's

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idea of behavioral activity, this reflects some level of engagement, but may still result in shallow cognitive effort. Instead, Chi suggests that constructive and interactive activities push the learner to create new knowledge. Constructive refers to the activities that elicit this creation within the learner; for example, generating predictions or comparing/contrasting examples. Interactive refers to the co-creation of understanding between a learner and an instructor, such as discourse or collaborative problem solving. These two types are analogous to Mayer's idea of cognitive activity, as they both involve a behaviorally engaged learner, who is also intellectually stimulated.

Although early models of discovery learning painted the picture of a learner working more or less independently,[2] the ideas of Mayer and Chi as well as recent empirical findings[8] support the inclusion of some guidance during discovery learning. In the following section, we discuss evidence supporting three approaches for guiding discovery learning in children: (1) strategic presentation of materials, (2) consequential feedback, and (3) probing questions and self-explanations. These general approaches have been identified and selected for several reasons. First, each represents an opportunity to facilitate guided discovery learning. Second, these three approaches reflect distinct and important time points in the learning process. The first approach focuses on initial problem/task experience, the second reflects immediate post-solution assessment and the third approach deals with subsequent refinement and restructuring of concepts and strategies.

Third, each of these approaches can increase cognitive activity[5]and reflect the principles of constructive or interactive activity between the learner and an instructor.[7] Finally, each is supported by empirical data with children of varying ages. It should be noted that while we will focus on data from children between the ages of 4 and 12 (pre-school through elementary school aged children), these approaches are certainly applicable to older or even younger learners as well. In the evidence that is summarized below, we will focus on examples from the domains of scientific reasoning/problem solving and mathematics. These domains were chosen because they are generally problem-based and require the application of abstract concepts on specific problems or examples. The approaches discussed here lend themselves to this type of structure.

STRATEGIC PRESENTATION OF MATERIALS

Careful selection, structuring, and presentation of problems or tasks can be the effective means to facilitate guided discovery learning. In approaching a new domain or concept, the learner may not realize which aspects or details need to be focused on. An instructor can reduce complexity, maximize learning, and/or minimize misconceptions by strategically selecting and presenting problems and examples.[9] In the Montessori philosophy,[10] this finds expression in the concept of *prepared environments*, which refers to classroom environments designed to provide children with materials they are cognitively ready to explore and use to develop skills. Thus, it is not simply a matter of what the child is provided, but also the manner, timing, and context in which it is presented.

The moderate-discrepancy hypothesis offers a mechanism for the benefit of such environments: children's tendency to attend to information just above their level of understanding.[1,11] This interest can help facilitate learning by discovery if experience is provided in an appropriate range. For example, children are capable of discovering new rules for solving problems on the balance scale task,[12,13] a paradigm that requires attention to two physical dimensions: the number of weights on each side of the scale and the distance of the weights from the scale's fulcrum. By age five, children typically make predictions based on weight, but not distance. However, they can more easily discover the relevance of the distance dimension if they first learn the impact of weight.[13] Therefore, experience with distance-related problems provides appropriate fuel for learning, but only for children who already understand the weight dimension. These findings point to the importance of *when* an experience is provided as well as *what* that experience is.

Related to this, Bjork[14] refers to 'desirable difficulties'—challenging contextual factors that take advantage of the learner's current state of understanding and push him/her further in the learning process. Among these he includes practice or problem-solving sessions of mixed problem types rather than blocked sessions of a single type. The technique provides the learner with appropriately challenging and diverse circumstances that will lead to improved understanding without explicit instruction. Chen[15] examined the effects of experience with mixed problem types on schema induction in elementary school children (ages 8–11). Children were presented trials of Luchins' Water Jar problem, which requires the problem solver to achieve a certain unit of measurement by combining three different measurement devices (e.g., cubes, blocks of differing length). To succeed, the problem solver has to recognize that a certain solution equation underlies the problem (e.g., $1A - 2B + 1C$). Children who received a diverse set of problems that shared a general principle showed deeper and more flexible learning (as measured by greater success on test problems) on the task compared to children receiving learning problems with more homogeneous solution procedures. This suggests that the diversity of provided learning examples can have a robust effect in facilitating the discovery learning process.

Another strategic presentation technique for supporting guided discovery is comparison of examples. As a cognitive process, comparison has been shown to help learners attend to relations between attributes,[16] develop abstract problem-solving schemas,[17] and facilitate new interpretations of information.[18] This has been demonstrated in a variety of domains and age groups, from infant category learning[19] to undergraduate psychology.[20] Such comparison may be particularly beneficial in mathematics, where problem features and variables can vary systematically. Rittle-Johnson and colleagues conducted a study with seventh and eighth grade students to look at the advantages of comparing math problem examples side-by-side versus sequentially.[21] Learners who compared differing methods to solve the same problem showed increased gains in procedural knowledge and flexibility compared to those who examined problems in isolation. In a subsequent study,[22] they demonstrated that comparing distinct solution methods applied to the same problem led to superior learning over different problems being solved by the same method. In line with the moderate-discrepancy hypothesis and the findings summarized above,[13] they also found children with prior knowledge of relevant concepts benefited from the comparison process in contrast to those without prior knowledge. Again, this highlights the need to tailor guidance to the particular learner.

These studies show the value of comparison as a tool for the strategic presentation of learning materials. However, they also show the importance of a sensitive understanding of the student's readiness to learn and benefit from comparison. In addition to presenting materials to maximize guided discovery, the instructor may provide verbal prompts to facilitate this process. In addition to presenting materials in a comparative fashion, Rittle-Johnson and Star[22] provided learners with specific questions to facilitate this process (i.e., highlight comparison of problem type versus solution method). Therefore, the mere provision of comparable examples may not be sufficient to induce learning. A sensitive teacher must also structure the comparison process with appropriate verbal cues and probes.

In summary, experiencing diverse problem examples and engaging in active comparison prepares the student for further learning by highlighting important features and principles. This highlighting can then facilitate other higher-level learning processes (e.g., elaborating, analogizing, transfer of knowledge, etc.). It may also help students break rigid mental sets and brittle representations of the topic by seeing an issue from multiple perspectives. Although comparing examples may be part of guided discovery learning process, it is also beneficial to see such techniques can lead to a mind that is more prepared to learn in a traditional lesson setting (i.e., creating a 'time for telling'[18]).

CONSEQUENTIAL FEEDBACK

Feedback is a broad, yet critical concept in the science of learning (For review, see Ref 23). This general approach to facilitate guided discovery refers to either direct responses from the tasks/problems themselves or from the instructor that occur following the learners' solutions as a consequence of the learners' efforts.[24] Its function is to highlight mistakes, illustrate faulty strategies, provide hints/cues to misconceptions/faulty strategies, and thus prepare the student for further learning.[11,18] It may occur during the course of experience, through the implementation of a child's ideas and efforts. For example, a 3-year-girl fails to use a tool to obtain a toy beyond reach; she then notices her arm is too short before she discovers a tool-use strategy that involves using a rake to extend her arm.[25] In this case, unmediated experience provides feedback and drives the learning process. During scientific experimentation, feedback received from viewing the outcome of generated experimental tests is critical to learning how to disconfirm or support hypotheses.[26] Repeated experimentation provides the child with opportunity to implement ideas and strategies and assess their correctness or effectiveness through the resulting outcomes.

Though feedback resulting from such experience can be beneficial, it may not always lead to learning when errors or misconceptions occur, especially when errors are not evident or the metacognitive abilities of the learner are low.[27] In the absence of more explicit feedback, the learner may continue to hold incorrect beliefs.[28] Furthermore, if a child uses an ineffective or inefficient strategy, experience alone may not highlight and correct this.[29] In such situations, explicit feedback from the instructor is necessary to scaffold further improvements. For example, in numerical estimation tasks, young school children tend to demonstrate a nonlinear representation of numerical magnitude.

Opfer and Siegler[30] found that providing experiential feedback in the form of the experimenter providing correct answers following the child's answers led to rapid representational change toward a linear understanding of numerical magnitude. Such feedback could not occur through attempting problem trials alone; it requires a careful scaffolding and input of an instructor. However, such input does not constitute traditional instruction, as the feedback only occurs following the child's efforts and does not consist of elaboration on underlying concepts.

A recent study on children's learning to generate a conclusive test for a hypothesis demonstrates the benefits of multiple sources of feedback on learning.[31] Kindergarteners through second-grade students were told a story in which they had to determine whether a big mouse or a small mouse had been eating food in the kitchen at night. Children were told that they could place food in either of two boxes: one with a big opening that could accommodate either a large or small mouse, and one with a small opening that could accommodate only a small mouse. Selection of the smaller box reflected a conclusive test, as only one of the two sizes can fit. Children were then tested on three isomorphic versions of the task and were assigned to one of two kinds of feedback: (1) physical feedback, in which the child was given a physical demonstration of a correct and an incorrect answer using props and (2) verbal and physical feedback, where the experimenter gave a demonstration with the props and also elaborated on the correct choice. In the second condition, children received corrective feedback on their efforts and were given a brief explanation on why one choice was correct. Following feedback, children in both conditions were given further problems to solve. The results of this study suggest that children who received verbal and physical feedback learned most effectively. This suggests that in some circumstances, a combination of both types, i.e., experiential and verbal feedback may be most effective. The provision of such feedback under the supervision of a teacher or tutor has long been seen as a beneficial tool in developmental and educational theory.[6]

These specific findings point to the efficacy of consequential feedback guiding learning by discovery. More broadly, meta-analytic findings suggest feedback (in comparison to no instructional intervention) has a significant effect on learning. Kluger and DeNisi[32] examined 470 effect sizes and revealed an average positive effect of approximately 0.40. However, this analysis was not focused only on young learners and reflected many types of feedback, domains, and tasks. The authors also point out that feedback should not direct focus away from learning. That is, learners should not become fixated on the feedback as an end, but a means. Rather, it should serve as a guide to improved understanding.

Although many aspects of education may contain feedback (e.g., praise, rewards, and grades), consequential feedback refers to that which is corrective and occurs following problem-solving efforts.[24] Depending on the domain or task, mere experience may highlight misunderstandings or alternative strategies. However, in tasks where these are not apparent following solution efforts, the instructor may need to consider more direct modes of providing clear assessment information to guide future efforts.

PROBING QUESTIONS AND SELF-EXPLANATION

Another critical approach to guide discovery learning is the use of probing questions to direct student's attention to important features in a problem or example. Systematically, asking questions can direct the learner's attention to important features in a problem or example and may also illustrate misconceptions and mistakes. Chen and Klahr[26] compared and contrasted 7- to 10-year-old's learning of strategies for designing valid experiments in two conditions. The conditions differed in whether the experimenter asked children a series of questions to explain why they designed a particular test and how they would interpret the experimental outcomes. Children benefited from systematic questions designed to promote deeper discovery and learning. In contrast, allowing a child to interact freely with experimental materials/devices without asking guiding questions did not promote discovery and transfer.

Related to the approach of probing questions is the technique of encouraging the learner to generate examples of an idea. In this case, an instructor may present a general or abstract idea to the student and then ask him/her to come up with instantiations of it. Previous studies suggest both adults[33] and elementary school children[34] are capable of generating examples and inferences from an abstract principle or exemplar. For instance, encouraging students to generate concrete examples for abstract principles has been found to enhance understanding of the concepts and facilitate subsequent transfer.[35,36] Research from the analogical reasoning literature also suggests novice learners can be susceptible to recall superficial similarities between examples of problems.[37] In contrast, when required to process information by generating examples, they tend to use underlying structural information.[33,38]

Another questioning technique involves asking children to explain their own reasoning during or after solving a problem. This technique can be considered part of guided discovery learning as the educator is typically responsible for asking the learner directed questions designed to facilitate insight about key aspects of the problem at hand. Self-explanation has been found to promote learning and transfer in a number of studies (for a review, see Ref 39). The underlying process that drives this benefit is one of identifying and filling in gaps of understanding, focusing on relevant processes, and planning ahead.[40,41]

Rittle-Johnson[42] examined the effect of self-explanation on learning of mathematical equivalence (e.g., $2 + 7 = 8 + 1$) in elementary school children. Half of the children in the study were asked to explain the correct or incorrect procedures of another person. Requests to self-explain led to better learning and transfer. However, this improvement was restricted to measures of procedural knowledge, not conceptual knowledge. Children who self-explained were more likely to invent procedures for solving equivalence problems and were more flexible in their strategy use across diverse types of problems.

Research points to varying benefits for self-explanations, depending on their focus. For example, learners may be asked to explain their own efforts, whether correct or incorrect. For example, Siegler and Chen[43] examined the benefit of self-explanation on children's learning of the water displacement task. Children were shown problems where objects varied by weight and volume and were placed in a jar of water. The outcome of the problems varied, with some objects floating and some sinking. Children's understanding was evaluated at pre- and post-test. In between these phases, children received a learning phase that varied between three conditions. A one third of the children were asked to explain outcomes where their predictions were either correct or incorrect. A one third of them were asked only to explain correct predictions. The remaining one third were not asked to make explanations after seeing the outcome of a problem trial. The results showed that asking children to explain both correct and incorrect predictions was most conducive for learning. This suggests the act of searching for underlying causes in successful and unsuccessful attempts contributes to learning by discovery.[39]

Self-explanations may also vary in whether learners are asked to explain their own reasons for an answer or explain correct answers given by the educator that may diverge from the learner's understanding. Siegler[44] also demonstrated the differential effectiveness of self-explanation in a study on learning about conservation reasoning. Five-year-olds were presented with conservation of number tasks and asked to compare the relative length of two rows of objects. After giving an answer, children either (1) received correct/incorrect feedback, (2) were asked to explain the reasoning of their answer before receiving feedback, or (3) were given feedback and then asked to explain the experimenter's reasoning. This final condition was most interesting as it provided guidance in the form of feedback and yet required the learner to think further about the underlying reason for the correctness of an answer. Siegler found that this last condition led to the greatest amount of learning, especially on the most difficult conservation problems. Being asked to explain the reasoning behind another's answer may push them to re-examine and re-represent the information at hand.[45]

In the implementation of this technique, questions also exist as to whether explanations that are self-directed are more effective than those directed at another. It may be that self-directed explanations are more effective because they highlight what is not known or poorly understood, whereas explanations to another tend to be focused on what is already understood. In effect, self-directed explanations may serve to focus attentions on misunderstandings in need of repair.[46] However, there are reasons to believe that providing explanations to others may be more beneficial than self-directed explanations. Rittle-Johnson and colleagues[47] examined self-explanation effects on 4- and 5-year-olds learning of a classification task. Children were asked to make either self-directed explanations or explanations directed to their mother. Children in the latter condition showed the greatest improvement. The authors suggested that an audience may push the learner toward greater explicit awareness of the relevant issues at hand or prompt the consideration of alternative ideas.

The studies summarized above suggest a benefit from self-explanation; however, questions remain as to its effectiveness. How impactful is self-explanation on learning? Durkin[48] conducted a meta-analysis of self-explanation effects in learning mathematics. Though not focused only on children, 5 of the 18 studies included involved participants between the ages of 5 and 15. The findings suggest that the self-explanation effect, though significant, was small (overall standardized mean effect size = 0.37). Mugford and colleagues[49] conducted a broader meta-analysis of 30 studies from a variety of domains (i.e., math, science, and engineering). They too found a significant, but moderate, effect for self-explanation ($\hat{g} = 0.39$). Both meta-analyses noted considerable variability in the impact of self-explanation across the various studies examined due to the variety of ways it was implemented.

Despite these effects, future research is needed to provide greater understanding of the efficacy of self-explanation. Concerns remain as to which learning contexts it may be appropriate to use it in.[50] Empirical evidence raises questions about whether self-explanation is superior to instruction.[51] Matthews and Rittle-Johnson[52] examined the influence of both in second- through fifth-grade children's learning to solve mathematical equivalence problems. They found more robust effects for instruction overall, although self-explanation used in concert with instruction was effective. These findings suggest that self-explanation may work best with other techniques of discovery learning guidance.

In summary, following learners' efforts at problem solving and any subsequent feedback, techniques exist for instructors to guide learning, even in the absence of direct instruction. By asking probing questions, requesting self-generated examples, and asking for self-explanations, the instructor may help the student to examine misconceptions, assess limits of understanding, and plan for future problem-solving efforts. Such techniques can be classified as constructive, as they require a degree of collaboration between the instructor and learner.[7]

CONCLUSION

In contrast to the traditional view of discovery learning, in which learners behave autonomously in the learning environment, more recent research provides clear evidence that guidance should be strategically included in the discovery learning. The present review points to three general approaches which have been shown to facilitate guided discovery. More empirical work is needed to explore the conditions, contexts, types of tasks, and timing when each approach and technique can be implemented for maximal effectiveness and to identify the types of knowledge that can benefit from guided discovery learning practices. It should be pointed out that much of the evidence provided here comes from experimental laboratory studies in which learning conditions are highly controlled. In addition to the need for a greater understanding of factors that lead to successful discovery learning, future efforts are needed to maximize the potential 'implementation fidelity' of a guided discovery curriculum (Ref 53, p. 303).

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