Leveraging Cognitive Psychology Principles to Enhance Adaptive Instruction

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Abstract. Intelligent Tutoring Systems (ITSs) can be used for computer-based adaptive instruction that can be utilized in many ways including both in the classroom and on a student's own time. ITSs can be particularly useful for remediation and confirming that a student fully understands a topic that is important in an educational course. As many individuals will be using ITSs on their own time, and it is a unique opportunity to customize to an individual, it is helpful to design the material that is being delivered to the student to be as memorable as possible. There are numerous strategies and theories within cognitive psychology that have been heavily researched, and lead to improved memory, and retention when put into place. The current paper discusses how these cognitive psychology strategies can be leveraged and utilized within ITSs in order to lead to improved outcomes. Additionally, there are suggestions on how to incorporate these strategies within ITSs.

Keywords: Intelligent Tutoring Systems · Cognitive psychology
Adaptive instruction

1 Introduction

Intelligent Tutoring Systems (ITSs) provide computer based adaptive instruction to students that can be used as a main instructional tool, an in-class activity, or a way to supplement instruction. An advantage of ITSs is that they are flexible, and customized to the individual student and their instructional needs. It is anticipated that by having a student interact with a highly adaptable computer based learning system which targets the material that they need instruction and remediation on that it will lead to positive learning outcomes and retention of material. While in most ITSs there are many built-in instructional strategies that are intended to enhance retention, there are other less traditional ones that can be utilized in the creation of materials for ITSs, as well as strategies that could be implemented in the future in ITS frameworks.

In cognitive psychology research there have been a number of different activities and principles that have been identified that can enhance the memory that an individual has for information. Among these approaches are the self-reference effect (encouraging the student to link the information to him or herself), heuristics (natural short-cuts and misconceptions that individuals make that lead to quick decisions), mnemonics (memory strategies) and context-dependent memory (improving memory when the context for learning and recall are the same).

D. D. Schmorrow and C. M. Fidopiastis (Eds.): AC 2018, LNAI 10915, pp. 69–77, 2018.
https://doi.org/10.1007/978-3-319-91470-1_7

The principles and strategies that have been identified in cognitive psychology can be utilized in the creation of learning materials that are provided in an ITS. Many of these cognitive psychology principles can be adapted and applied in a computer based environment to enhance ITSs and ITS frameworks. By incorporating strategies from cognitive psychology into ITSs, they could be used to provide remediation to learners, as well as assist in memory for and retention of learned information.

Examples of leveraging one of these strategies is utilizing the self-reference effect by collecting information about the individual student and storing it in the system as a variable for later inclusion in ITS generated examples and questions. In the current paper different cognitive psychology principles that encourage memory and recall will be discussed, as well as approaches that can be used to harness them in adaptive instruction to enhance human memory and performance. Further, a discussion will be provided identifying different types of memory, and how ITSs as well as their instructional materials can be created to best leverage the way that information is processed.

1.1 Cognitive Psychology

Cognitive Psychology is a subarea of psychology that focuses on how information is processed by humans. One of the defining characteristics that separates cognitive psychology from other areas, is that many of the ideas are abstract and theory driven. For example, we know that the brain retains information, but we do not necessarily know how it does so. There are many theories in cognitive psychology that are used to explain memory such as the modal model of memory, which includes sensory, short term, long term memory [1]. While the different types of memory are generally agreed upon, an area such as attention has more completing theories. For example, memories of attention range from the mechanisms that describe bottlenecks and filters that information need to pass [2], to spotlight theories that use a stage spotlight as a metaphor of what can be focused on [3]. Regardless of the theory that is subscribed to, there are generally "effects" or evidence that is present in the literature that appear to account for improving memory or leading to improved attention. For instance, the "cocktail party effect" is highly tied to attention research. In the cocktail party effect, it has been found that a person's name can break into attention even when they are engaged in a high workload audio task [4]. This finding can then be applied in new ways such as in emergency alerts [5] or in the cockpit of an airplane. In many ways, cognitive psychology is a discipline that is more abstract, but can be applied in related areas such as human factors psychology or educational psychology.

1.2 Cognitive Psychology and Intelligent Tutoring Systems

As noted, cognitive psychology focuses on the ways that the brain processes information and through research has identified ways that people link information together and process memory. By leveraging the research and "effects" that have been identified in cognitive psychology research it can have a positive impact on learning, particularly in a computer based adaptive system such as an ITS. The approaches can be applied in two ways to assist in learning: (1) as a design principle in the materials and questions that ITS authors create, and (2) as strategies that are implemented within an ITS framework that will then present material in a way that is consistent with cognitive psychology principles that have been identified as helpful to memory. In the current paper, principles of cognitive psychology that are applicable in an ITS context will be identified, and recommendations will be provided on how they can be utilized to enhance adaptive instruction and ultimately memory for the content that is being taught.

In general, ITSs are made up of four components: a learner module, pedagogical module, domain module, and a tutor-user interface [6]. As an illustrative example, throughout the paper the ITS framework, the Generalized Intelligent Framework for Tutoring (GIFT) will be used to provide context for the recommendations that are provided. GIFT is a domain-independent ITS framework that includes the traditional modules, as well as a sensor module (to allow it to gather data from external sensors) and gateway module (to allow it to communicate to external computer programs) [7]. As GIFT is domain-independent, it provides a structure for the ITS, which is then populated by the course instructor, or ITS author using a set of authoring tools. The ITS author will bring all of his or her own instructional materials and questions to enter into the system for use during tutoring. GIFT is a research project, and is constantly being updated. Therefore, any of the suggestions provided in this paper could be applied in future iterations of GIFT. For instance, the pedagogical module within GIFT provides remediation material and strategies based on a literature review [8]. Strategies that are identified from cognitive psychology could be used to update the types of strategies that are used by the pedagogical module in GIFT.

2 Identified Cognitive Psychology Principles

While there are numerous cognitive psychology principles that exist and can be utilized to improve memory, the current paper will discuss a sample of them and provide examples on how they can be particularly tied into computer-based adaptive instruction. The discussion will begin with an explanation of common theories of memory.

2.1 Theories of Memory

Modal Model of Memory. According to the Modal Model of Memory [1] there are three types of memory: sensory memory, short-term memory, and long-term memory. Sensory memory exists in both the visual and auditory form for an extremely short amount of time. If the sensory memory is paid attention to, then it can transfer to short-term memory, which is where memory is temporarily stored prior to it being moved to long-term memory, where is it is retained by the individual. In general, it is believed that rehearsing, or working with the information, will assist in moving it from short-term to long term memory. Some of the evidence for this is found in the serial position effect [9]. If an individual is provided with a list of information, they have a tendency to recall the information based on the order in which it was provided to them. For instance, the information about the beginning of the list is well remembered because it had an opportunity to be repeated over and over again by the individual (the primacy effect; [9]). Additionally, the information at the end of the list is also remembered by the individual since it is still in short term memory (the recency effect; [9]). Combined, the primacy and recency effect make up the serial position effect.

The serial position effect is an example of a strategy that can be utilized in both the design of ITS material, and within an ITS framework. If an author identifies that the material to be learned is highly repetitive or list based, then the ITS system could intentionally be designed to tutor the middle items or steps in a sequence to ensure that they are recalled to the same degree as the others. For a more generalized approach to harnessing the way that memory works, it would be helpful for the ITS author to keep in mind that working with and processing information in short-term memory can ultimately move it to long-term memory. Therefore, it would be helpful to author materials that include reminders of information that was previously learned, and provide checks on learning that require the learner to use information that they have recently learned.

Additionally, one way to approach facilitating the use of appropriate strategies in an ITS would be to provide the author with an authoring tool interface that asks questions about the characteristics of the material to be taught. For instance, if the author is asked if the material is "list-based" or if "order matters", then perhaps the ITS could select this as an appropriate approach for them to use and auto-populate the information that is entered by the author in the system.

Working Memory. Baddeley's model of working memory [10] builds on the Modal Model of Memory. According to Baddeley's model, as opposed to having a static short-term memory store, humans actually have an active short-term memory that is actively used for thinking and processing of information. It has been shown that the capacity of working memory is approximately 7 plus or minus 2 items [11]. This research has been applied in the form of the length of phone numbers. Baddeley describes working memory as being made up of three components: the visuospatial sketchpad (which deals with visual information), the central executive (which determines what needs to be paid attention to/allocates resources), and the phonological loop (which deals with auditory information) [12]. Research that supports this model has shown that individuals have difficulty processing two types of visual information at the same time, but can process visual and auditory information simultaneously [12]. This suggests that they are separate processes, and that when designing a task it can be helpful to separate visual and language based tasks to have maximum attention and retention. An example of the application of working memory in the real world is, that in driving research that has found that talking on the cellphone while driving impacts driving performance [13]. One explanation for this is that the visuo-spatial sketchpad is being double taxed by the visual driving task, and the visual metal imagery task that is related to the conversation that is occurring.

Per the application of this research, when designing content in an ITS, it may be better to design instructional materials such that any interactions do not double tax the same working memory resource. For instance, if the individual is being tutored in a simulated driving environment it would be preferred to provide tutoring feedback in auditory form as opposed to visual form, and to focus on simple topics as opposed to language that elicits visual images in the learner's mind. If both the task and feedback are in visual form it may pull the attention of the individual from the task, and it may overload them. In this situation the auditory channel is not yet being used, so it may have better results, especially if the materials provided are straightforward. In an ITS authoring tool it could ask the author about the characteristics of the task, and provide recommendations based on the type of task. For instance, if it is an auditory task, it may recommend visual feedback, and vice versa.

2.2 The Self-reference Effect

The self-reference effect has shown that if information is tied to the self it is easier to recall than if it is not [14]. By integrating strategies and functionalities into an ITS such that it can reference the individual by name it may be able to leverage this effect for better learning [15]. Sinatra and colleagues designed a tutor for learning how to solve logic grid puzzles, and varied the types of names that appeared within the content of the material during learning [16]. Participants either received the interactive tutorial with their own name and the names of friends (to encourage self-reference), names of popular culture characters or generic names included in the text of the tutorial and puzzle that was being used for learning. The idea behind this was that by utilizing one's own name in the material they would potentially learn the material more deeply and be able to transfer their skills more successfully. Interestingly, individual differences played a role with those who were high in need for cognition performing as expected in the conditions when the manipulation occurred during learning (although it was not significantly significant), with best performance with self-reference, and worst performance with generic names. However, those who were low in need for cognition actually performed better when popular culture names were used, and worst when their own names were included. This is an important finding, as it appears that individual differences such as need for cognition can impact how effective or non-effective a strategy is when it is applied.

Providing a way for authors to include the names of individuals within materials could have a positive impact, especially for students who are high in need for cognition. One approach to being able to harness the self-reference effect, would be to use an approach within the ITS that stores a variable, such as the learner's name. When the learner enters their name into a survey in response to a question, the system can then store the variable and reference it later on in material, questions, and instructions. This can results in learners feeling that the material is more personalized, as well as leveraging any potential self-reference effect that exists. It may be helpful to have options with the authoring tools that provide question types that the author can use to create variables that can later be reused in questions and throughout the tutoring instance. Further, in the case of GIFT the self-reference effect could be implemented as a strategy that is recommended when learners score high on a need for cognition scale, but not those that score lower on it.

2.3 Heuristics

Heuristics are rules of thumb that individuals use to help them make quick decisions. However, the use of heuristics do not always result in the correct answer. There are many different common heuristics that individuals use, but for the purpose of this paper two will be discussed in regard to their relationship to ITSs. Heuristics such as the framing effect and the sunk costs effect can be applied to ITSs in different ways. According to the framing effect, the way that a question is phrased will influence the response that an individual provides. For instance, if a question is formed in terms of gain, individuals are more likely to agree that it is the right choice than if it is phrased or "framed" as a loss [17]. The sunk costs effect is also relevant in terms of an ITS in a different way. According to the sunk costs effect, if an individual has already spent time or money on something, they are more likely to continue on with it even if it no longer makes sense [18].

With the framing effect in mind, an ITS author or instructor should be mindful of the way that he or she phrases questions that are being used during the tutoring session or for assessment that will lead to remediation. It is important to differentiate between if the learner does not understand the question or if the question is phrased in a way that will naturally lead the learner to provide a specific answer. This is particularly relevant when tutoring and assessing a topic such as logic, which may ask the learner to choose between two or more answers. If the phrasing of the answers is as a gain or loss it may impact their response. The framing effect may result in individuals consistently providing the wrong answers, and going through unneeded remediation in the tutor. Therefore, it is important to avoid common reasoning errors that individuals may make during the authoring of tutor assessments.

The sunk cost effect can be applied in different ways in ITSs. If an ITS is structured such that learners have an opportunity to select their own topics and provide the order that they will be engaging with the material in there is the potential for them to engage with the sunk costs effect. For instance, if a student is repeatedly misunderstanding and failing questions about a specific concept, the tutor may continually push them back in through remediation and not allow for them to move on until they have been successful in completing it. Since the learner has spent a great deal of time with the system he or she may feel that it would be advantageous to continue pursuing mastery of the topic, but this may be at their detriment because they are unable to move on to additional material that they may be able to master. Therefore, it is important to be mindful of the way that an ITS is structured such that it will not necessarily keep pushing learners through the same material if they are not achieving it, and it may provide reminders to learners to continue on to other topics if they are by choice continually repeating a topic.

2.4 Mnemonics

Mnemonics are strategies that can be used by individuals to help them remember information. Mnemonics can be as simple as creating an acrostic from the first letter of the words that need to be remembered, or as elaborate as remembering items by associating them with specific locations and taking a mental walk through a familiar environment to recall the list (the method of loci). Research has suggested that using the method of loci in a virtual environment has similar results as using it in a conventional familiar real environment [19]. Similar to the method of loci is pairing two images together and imagining them when it is time to recall them. For instance, if the individual needs to remember an iguana and a book, it may be helpful to imagine the iguana sitting on a book.

If the task that is being tutored is heavily memory based, then the ITS author may want to pair different images together to assist the learner in remembering the items. This can be achieved in an ITS through authoring materials that show the necessary images together. Further, it can be tied to procedural knowledge and route knowledge by tying the step that the individual needs to engage in with another interesting image which can then serve as a retrieval cue to assist with their memory. For instance, if the learner is being taught about how to navigate a path in the environment he or she can be prompted to imagine other items or images in the locations where they need to make turns. Using the iguana example, it may be helpful to show a drinking fountain with an iguana on it, followed by a staircase with a turtle on it. Then when the individual navigates the actual environment within a simulation he or she can recall where the important turns are based on recalling the interesting item that they had previously associated with it.

2.5 Context Dependent Memory

The idea of context dependent memory is rooted within cognitive psychology research. It has been found that when information is recalled in the same setting it is learned, then there are better results [20]. For instance, based on this idea, if an exam was given in the same room that the lecture occurred in, students would likely perform better on recall than if the exam was given in a different room.

This can be applied in ITSs by providing customization for the pages that are used for assessment. For instance, if the author provides the information on a page with a blue background, then can also choose to have their recall/exam on a page with a blue background, which would provide the same context that the material was learned in for the student.

3 Recommendations for Leveraging Cognitive Psychology Principles in Intelligent Tutoring Systems

In the current paper, principles and effects identified within the cognitive psychology literature have been highlighted. Additionally, the connections that these principles have to ITSs has been discussed. There are two main ways that these can be incorporated into ITSs, (1) through the authoring of material and structuring of associated authored questions by the course author, and (2) through implementing features and authoring tools within ITSs that allow for these strategies to be used. Certain principles lend themselves better to item 1, while others lend themselves more to item 2. In addition, it might be helpful to incorporate features and authoring tools into ITS frameworks such as GIFT to allow for these different principles to be harnessed by ITS authors who may not be familiar with them.

3.1 Initial Suggestions for Authoring Tools to Support the Use of Cognitive Psychology Principles in ITSs

As mentioned earlier in the paper, there are a number of different cognitive psychology principles that may have a positive impact on learning, but are not familiar to an ITS author or course instructor. One way to assist them in being able to use these strategies would be to create an optional ITS authoring tool or component of the existing authoring tool that an author can use to enhance the tutor that they are creating by using cognitive psychology principles.

The specific authoring tool could ask questions about the material that is to be learned, and based on those responses it could provide recommendations on approaches that can be used to author the material. For instance, if the author indicates that they are teaching vocabulary and definitions, then it can recommend that they author materials that focus on repetition and rehearsal. These recommendations of strategies could then be used to create the domain-dependent materials that will be used in the ITS. Additionally, in certain situations, such as when the material is largely question and survey based, the system could ask the author to enter their questions and then order them as appropriate based on characteristics of the questions (e.g., to harness the serial position effect if relevant), and in a specific order to ensure that material is rehearsed by the individual (e.g., to improve moving from short-term to long-term memory). This information that was entered could then be populated into a tutor, instead of the author needing to generate separate content. This authoring tool could also provide a means for authors to identify if they would like to use the learner's name throughout the tutoring (e.g., to elicit the self-reference effect), and provide a structure for the author to create questions that will use the names. In the case of GIFT, many of these features could either be built into existing authoring tools or as a separate tool to assist with course construction.

4 Conclusions

A great deal of research has been conducted in the field of cognitive psychology, and much of it is relevant to adaptive instruction as it highlights strategies for improving memory and learning. ITS authors can improve their tutors by being aware of different effects or principles that could help or hurt the memory retention that their learners have, and the creation of a potential authoring aid or authoring tool in an ITS system could assist them in creating content that is consistent with these principles.

Acknowledgements. The research described herein has been sponsored by the U.S. Army Research Laboratory. The statements and opinions expressed in this article do not necessarily reflect the position or the policy of the United States Government, and no official endorsement should be inferred.

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