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ABSTRACT

This report discusses the role of affect in cognitive processing. The importance of affect in processing mathematical information is described in the context of solving arithmetic story problems. Some ideas are offered about the way affective responses to mathematical problem solving situations influence the development, maintenance, and retrieval of information stored in human memory. A model of human memory based on schema knowledge structures is outlined. A way that affective information may be stored within a schema is suggested. The report concludes with a discussion of some affective responses to mathematics evidenced by students' comments as they worked with story problems. (PK)

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SCHEMA KNOWLEDGE FOR SOLVING ARITHMETIC STORY PROBLEMS: SOME AFFECTIVE COMPONENTS

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In this paper I discuss the role of affect in processing information about arithmetic story problems. I outline a model of human memory based upon schema knowledge structures, and I suggest how affective information may be stored within a schema. Comments made by students during interviews provide examples of different affective responses.

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In this report I discuss the role of affect in cognitive processing. The importance of affect in processing mathematical information is described in the context of solving arithmetic story problems. More specifically, I offer some ideas about the way affective responses to mathematical problem-solving situations influence the development, maintenance, and retrieval of information stored in human memory. I outline a model of human memory based upon schema knowledge structures and I suggest how affective information may be stored within a schema. The report concludes with a discussion of some affective responses to mathematics evidenced by students' comments as they worked with story problems.

The topic is introduced with descriptions of two affective responses to solving arithmetic story problems. Although the situations are hypothetical, they correspond in general to those that in practice elicit the two responses. The responses themselves are not hypothetical. I have observed them repeatedly in my own research and in anecdotes related to me by colleagues. The situations are useful in my later consideration of how affect influences cognitive processing and how it may be stored in human memory.

The Emotional Response

Imagine the situation in which a child is learning to solve arithmetic story problems. The child is presented with a problem and is asked to find the solution. The story problem is a typical textbook one having key words such as "altogether" or "have left". The child guesses that addition would be appropriate and carries out the addition algorithm successfully.

Suppose that the solution is correct and suppose that the child then attempts to solve another problem but does not get the correct answer. There are many ways for error to occur. Some of the words may have been misread or key words imagined to be present when they were not. An incorrect association between a key word and an arithmetic operation could have been drawn. The operation may have been correctly identified but be confused in the child's understanding with another operation. The operation may have been correctly chosen but have a bug in the algorithmic application. Finally, there may simply have been a careless slip or transcription error in the writing down of some of the numbers.

The child probably will not recognize what is wrong with the solution and will not understand why the answer to the previous problem was correct and the answer to the current one incorrect. The child believes that the same thing was done in both situations with the result that the child's actions were correct on one occasion and incorrect on another. What will the child's response be?

While a single error may not cause the child to experience emotion about problem solving, repeated episodes of this type may lead to a sense of frustration, a distrust of the child's own skills, or a general feeling of unease. The immediate feedback the child receives from parents, teachers, and peers may cause additional emotional reactions such as embarrassment or shame. These emotions, like other features of the situation, will influence the child's performance now and will also be encoded in memory as part of the experience of problem solving.

The Attitudinal Response

Picture this same child several years later in situations in which the child is required to solve story problems. Now, whenever the child is presented with a problem, the initial response is "I don't like story problems." Mere recognition of the situation is sufficient to trigger the affective response. The child does not need to be engaged in solving the problem.

This is an attitudinal response. It differs from an emotional one in at least two ways. First, the attitudinal response comes from the activation of previously stored affective memories. The emotional response comes about as the reaction to emotion that arises during the situation. Second, the attitudinal response is typically dispassionate (i.e., cold rather than hot). The emotional response may be an intense feeling accompanied in extreme cases by nausea, increased heart beat, or shaking hands. The attitudinal response, in contrast, does not usually activate observable physiological reactions. In this sense it is cold. It may still have an impact upon the child's willingness to engage in problem solving and may be itself sufficiently strong to block the child's attempts to search memory for appropriate techniques to solve the problem.

These are not the only two affective responses that can be observed in mathematics situations, but they are the most common. In the remainder of this report, I describe a model of cognition that accounts for how these responses are encoded in memory with other situational features and how their retrieval may influence the retrieval and activation of many aspects of problem solving.

THE ORGANIZATION OF HUMAN MEMORY INTO SCHEMA KNOWLEDGE STRUCTURES

Human memory has been described under several organizing principles. For example, Tulving (1972) talks about episodic versus semantic knowledge. Anderson (1983) focuses on procedural versus declarative memories. Hinton, McClelland and Rumelhart (1986) describe microfeatures in models of parallel distributed processing. What is common in these hypothesized knowledge structures is the general organization of long-term memory into networks. Individual pieces of knowledge are viewed as nodes in the networks. These nodes may be linked together or may exist as isolates. Retrieval of information from memory depends upon where the information resides within the network. Information that has many links to other nodes usually has a higher probability of retrieval than knowledge that is unlinked because there are more paths through the linked network. Access to an isolate node demands a retrieval path directly to the node itself. Access to a highly-connected node may be indirect, beginning with a node far removed from the target but connected to it over one or more paths through the network. In the latter case, access could begin with any of the connected nodes rather than only with the target node.

The network concept of human memory helps us to understand some of the research findings in studies of expert and novice performance. Experts appear to have rich, highly interconnected networks. Novices are more likely to have fragmented, partially linked networks, possibly with inappropriate links between nodes. Psychological studies of retrieval and forgetting also support the network structure of memory. Comparisons of recognition and recall demonstrate that it is easier to retrieve knowledge from memory given cues that allow multiple paths through memory nodes than from cues that lead only to a single isolated node.

During the process of retrieval, how are some nodes selected and others ignored? Psychologists suggest that the links between nodes carry measured impulses, either positive or negative. Thus, the <u>activation</u> of one node (perhaps through direct access) causes the activation of other surrounding nodes that are linked to the target. At the same time, this activation may also inhibit another set of nodes through negative connections.

It is a reasonable supposition that links between nodes vary in intensity. The degree to which activation spreads among nodes will be influenced by the strength of the associations that connect the nodes. Consequently, some nodes will receive a high degree of stimulation while others receive a lesser amount.

Through learning -- both intentional and incidental-- individual nodes are added to long-term memory and groups of them become connected. I hypothesize here and elsewhere that the primary mechanism under which these connections are made and by which meaningful learning occurs is the schema. A schema is a knowledge structure that allows the individual to recognize aspects of his or her environment and to operate on them, either abstractly or concretely. That is, the schema governs the individual's interactions with the environment. Schemas are especially important in problem-solving situations because these situations demand responses of the individual, and schemas are the means by which these responses are constructed by the individual.

What constitutes a schema? In earlier research, I have developed a model of the schema built upon four basic components (c.f., Marshall, Pribe, & Smith, 1987). First, there is a generic representation of the situation to which the schema applies. This component contains all of the facts, descriptors, and embellishments about the general instance in which the schema will be used. Related to this is the second component that consists of the restrictions and conditions that must be met if the schema is actually to be instantiated. Thus, the first component has the general description and the second has the tests of goodness of fit of the description to the current situation. The third component contains planning mechanisms related to implementing the schema. Within this component are particular goals and sub-goals that may be expected as well as general goal-forming procedures. Finally, the fourth component has the actions and procedures that govern the actual implementation of the schema.

In a fully developed schema these four components would each be subsets of interconnected nodes, with links running between components as well as within them. Initial access to the schema could be through any of the four subsets, resulting in activation of the entire set of nodes that define the schema. Thus, faced with a problem, an individual might first recognize the general form of the problem (component one), might notice initially the presence or absence of a particular constraint (component two), might focus upon the obvious goals and secondary goals that must be achieved prior to solution (component three), or might identify particular actions that would be appropriate to the situation (component four). Each of these would activate the others. The depth to which any component might be activated and accessed by the individual depends upon the complexity of the problem. Trivial problems require little cognitive processing. Difficult ones might involve access to many different schemas.

This conception of memory organization has been applied mainly to the acquisition and storage of knowledge as it relates to cognitive skills. In particular I have developed the model with respect to the knowledge required to solve arithmetic story problems (Marshall, Pribe, & Smith, 1987; Marshall, 1987). It is my purpose here to extend the model to include affective components of problem solving as well.

AFFECTIVE LINKS IN THE SCHEMA MODEL

There are at least two means by which affect can enter schema knowledge. The affective features of the situation may be learned at the same time that other features of the schema are encoded. Alternatively, the affective response to the situation may be developed after the schema is fully formed and be, in effect, a secondary encoding related to the pre-existing schema. I will consider each of these separately.

Simultaneous Encoding

Return to the first situation described above. While solving the first story problem, the child encodes in memory certain aspects of the situation. Because the child is learning to solve these problems, he or she does not already have a schema that will guide and structure a response to the situation. The process of making the decision to add and of carrying out the algorithm creates weak bonds among features of the problem situation, such as the key word "altogether", the process of making the choice of operation, and the action of carrying out the computation. Further, if the child's answer is correct, another node may be linked to the others indicating that tasks such as these are not difficult or are even pleasurable.

As the child encounters the second problem and makes an error, the link to the positive affect node will be weakened and a competing link will be formed with a negative affect node. Repeated failures will strengthen this link. Repeated successes weaken it and strengthen the positive one.

For a single problem, the child is unlikely to encode an affect node unless the situation is exceptionally threatening or rewarding. However, if the child continues to attempt to solve problems and continues to err, a node of negative affect will be encoded, strengthened, and linked to the problem-solving process. With repeated failures and frustrations, the affect node becomes stronger and its links to other features of the problem situation also become stronger. Eventually, one predicts that the presentation of a story problem will evoke a strong negative reaction from the child because the schema itself has been created in the presense of the affective response. In this case, affect is a feature of the situation and has been encoded along with other features.

Encoded in this way, the affect node is a multi-connected one with links to many other nodes in the schema. It is not an isolate that becomes activated alone. Just as with any other feature of the problem-solving situation, it will have stronger links to some nodes and weaker ones to others.

Where in the schema structure can affect nodes reside? That is, to which other nodes will affect nodes be strongly connected? Since errors of solution can be the result of incomplete or inappropriate elements in any of the four components of schema knowledge, it seems reasonable that negative (and positive) affect nodes can also be found in any of the four components. For example, an individual may have developed an affective response to a particular type of algebra problem that was a source of difficulty in the past. Consequently, when faced with a problem that begins "Two trains leave New York at the same time ...", he or she immediately experiences a negative response. In this case, the form of the problem is part of the schema knowledge (the first component of general description) and the affect is linked directly to the encoding of <u>motion problems</u>. An equally difficult <u>mixture problem</u> ("Seth has 10 more quarters than dimes ...") may evoke no affect or even positive affect, depending upon the emotional aspects of previous problem-solving experiences.

Posterior Encoding

There appear to be cases in which individuals develop schema knowledge structures with little or no apparent affect links. One can imagine a competent mathematics student entering a mathematics contest and experiencing a negative reaction for the first time while attempting to solve a particular problem. This student will probably already have a highly developed set of schemas and be able to access them readily. Depending upon the strengh of the affective reaction to the current experience, the student may encode the negative affect in such a way that it links to the schema(s) as a whole. Thus, if the contest involves calculus problems, the student may develop an immediate dislike of all problems requiring integration. In this case, the affect node becomes connected to all parts of the schema. The schema nodes are already tightly linked and have probably achieved a level of activation that makes the instantiation of the schema appear automatic. When an affect node attaches to an existing schema, it connects equally to all parts of the schema. This bonding is in contrast to simultaneous encodings in which affect nodes are linked more strongly to the elements with which they were first associated.

It is reasonable that simultaneous and posterior encodings will lead to different outcomes for individuals solving mathematics problems. Part of the difference comes in the specific versus diffuse connections between affect nodes and other nodes. When the affect encoding takes place at the same time that other features are encoded, the links are specific, leading from one node directly to another. They are also relatively localized, extending primarily to nodes within one subcomponent of the schema. In contrast, posterior encodings lead to links that are more diffuse because they are formed between the affect nodes and the schema itself.

One can surmise that it may be easier to change affective responses that were coded simultaneously than to alter posterior encodings. Since the simultaneous encodings result from specific instances, they have links to identifiable parts of the schema. If positive experiences can be created that link to these same parts, a tension can be generated between the positive and negative responses to the same features of the problem. It is nice to think that many positive experiences could sufficiently weaken the older negative bond to the degree that the positive links would be dominant. Whether or not this is true is an empirical question and is an important research issue yet to be addressed.

EXAMPLES OF AFFECTIVE RESPONSES

There is some evidence consistent with the hypothesis that affect is coded as described above. This evidence comes from students' responses to open-ended questions about their problem-solving strategies and techniques.

Data Description

Several years ago I undertook a research project that necessitated interviews of approximately 100 sixth-grade children enrolled in two elementary schools. Each child was interviewed for approximately one hour. During this time, the child responded to a traditional paper-and-pencil test of ten story problems and then discussed with the interviewer an additional 10 story problems. Most of the problems required two computations for solution and involved whole numbers or fractions.

The children were asked to solve the problems on the paper-and-pencil test. They were not asked to find solutions to the problems discussed in the interview. Instead, they were asked to describe how they might solve these problems, to talk about making a plan to solve them, and to point out important information in them. A discussion of the students' success in solving the problems and an examination of the strategies they used are given elsewhere (Marshall, 1982). Here, I describe their manifest affective reactions to the interview.

The interviewer in this study was a soft-spoken young woman who relates well to children and interacts easily with them. She had worked with handicapped children and had also taught children with reading difficulties. It is evident from the audiotapes that she encouraged the children to verbalize their feelings as they solved the problems, although this verbalization was not an explicit objective of the original study.

Affective Responses

The children's responses during the interview were recorded in brief notes by the interviewer and were also audiotaped. The purpose of the original study was to examine the strategies used by sixth graders as they solved a set of problems. Of interest here is that most of the children volunteered affective information as well as details about their strategies (or lack thereof). The affective statements were interspersed throughout the interviews.

Positive responses. Most of the affective comments were negative, but there were some notable exceptions. One child made the following response, as she checked her answer to a problem requiring the use of fractions: "I was right ... it adds up ... this is fun!" . She went on to comment later on the relation between addition and multiplication and was very pleased to recognize and describe the connection. She enjoyed showing the interviewer how multiple additions would yield the same answer as a multiplication computation. These responses suggest that the affect is linked to the procedures she used in solving the problems. This is an example of affect within the fourth component of schema knowledge.

Other positive responses were less specific. One of the students responded very confidently "It's easy" to one problem and "This one's a little harder" to the next one. He later commented with enthusiasm to a third problem: "I don't know how to solve it but I know the answer." (He did have the correct answer.)

There are two different affective responses here. The first statements are examples of values given to the problems based only upon reading the items. The affect nodes here are attitudinal and are probably connected to the features encoded in the general descriptive component of the schema. The affective response was made prior to any attempt to solve the problem. The third response by the student is positive. Even though he was unable to describe the procedures, he was certain that he understood the problem and had the answer, and he was correct. How this affective information is encoded is unclear. The student's understanding of the problem and his solution may result from a highly automated and fully activated schema. Individuals are frequently unable to access specific features of automatic responses. The student's confidence implies that he understands the situation despite his inability to describe his solution strategy.

Negative responses. As might be expected from other studies of affect in mathematics, many of the students' responses were negative. Most of the responses could be classified as cold, reflecting attitudes about the situation. Nonetheless, there were some instances of obvious "hot" affective responses. For example:

Interviewer: Any idea about how to solve this one?

Child: I think. I think that she ... she counted 7 heads and 24 legs ... um ... I had something ... I think she counted ... okay ... 7 heads and twenty ... (pause, trails off) ... okay ... I think she ... okay ... she counted 7 heads and I think there were 14 um ... parakeets and ... (pause) ... 10 hampsters or whatever.

Interviewer: Okay, how did you get that?

Child: I went ... she had 7 heads so ... oh, my heart is beating so fast ... (trails off)

Interviewer: Are you scared?

Child: Yeah.

Interviewer: Why? This is okay. Just relax. It's all right. Okay? You're doing a tremendous job. You are doing very well.

Following this exchange, the child continued to talk about the problem and her solution to it. However, after solving two more problems her hands began shaking. The interviewer ended the session and spent several more moments reassuring the child that she had performed well on the tasks.

The majority of the "hot" responses were less dramatic. Several students reacted to the situation with steadily rising voices. By the end of the interview, these students were giving inflections to all of their statements, indicating a lack of confidence in their responses.

The most frequent negative affect was demonstrated in statements reflecting either a dislike of the task ("I hate this") or a self judgment of the child's ability ("I'm no good at this"). Responses of both types are consistent with stored affect linked to various schema components.

Few affective reactions could be attributed to the first component of schema knowledge described above. That is, students did not seem to have reactions to the general situations described in the problems. I hypothesize that such reactions are more likely to arise in other mathematics situations such as algebra or calculus. At the sixth grade children do not recognize situation similarities and thus would have no strong grouping of nodes to reflect the general description of various situations (Marshall, 1987).

There was evidence of affective links to other components of schema knowledge, particularly to the planning component. For example, one student routinely ended her comments about solving each problem with negative statements including the following: "This is probably wrong," "That's probably wrong," "I'm doing terribly." Most of these comments seemed to refer to her choice of operation and were made after she described why she elected to use a particular arithmetic operation. She did not voice hesitations as she carried out the computations. Thus, it is likely that the negative affect for this child is linked to the third component (the planning and goal-setting component) rather than the procedural component through which the actions are actually carried out.

Other children also expressed negative affective about making operation choices. One child commented, "I'm good with fractions but not word problems with fractions." Presumably this means that the child feels confident when told what operation to execute but is hesitant about choosing the operation when it is not specified.

Some responses seemed to indicate the presence of affective links with the constraints found in the second component of schema knowledge (constraints and conditions for using the schema). Several students expressed the belief that "They're trying to trick you" without specifying who _they_ might be. These students had difficulty understanding the problems. One said the following: "Oh, I hate these problems ... Why can't they just put numbers? ... I don't understand them ... I don't like these." Generally, statements such as these were followed by the student's pronouncement that he or she could not solve the problem and would like to move to a different problem. These responses appeared without any reference to planning or goal-setting considerations. That is, they attach to the second component of schema knowledge (the recognition of constraints that govern use of the schema).

Summary. The responses of these children provide evidence of both hot and cold -- emotional and attitudinal-- reactions. There were clear physiological indicators such as shaking hands, raised voices, and the self report ofincreased heart rate. There were also unemotional statements of dislike and inability.

Most of the affective responses were in accord with the model of schema acquisition and use outlined above. A tentative conclusion is that these responses support the simultaneous encoding of affect and problem features. There were some global responses to problem solving, but most of the children mentioned specific aspects that caused the distress.

Finally, it is encouraging that at least some of the students volunteered positive affective reactions. When students felt that they understood a problem and its solution, they spoke confidently and enthusiastically about solving it. For this group of students, positive affect appeared to be associated with their own self evaluations of understanding.

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