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ABSTRACT

This report discusses mathemagenic behaviors, which are activities that promote learning. During instruction these are the activities that learners perform when confronted with instructional stimuli. Three groups of hypothetic mathemagenic behaviors are discussed; translation, segmentation, and processing. A review of the literature on mathemagenic behavior, with 57 references, is given, followed by a discussion of the types of instructional materials and methods which have proved useful in integrating mathemagenic research with instruction in science. One implication of this research is that active behavior on the part of the student is essential. Also discussed are ways to translate physical stimuli into effective stimuli by the incorporation of the proper amount of structure into classroom activities, and ways teachers can capitalize on mathemagenic behaviors, such as using questioning techniques and activity-oriented laboratories. (MLH)

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REVIEW OF RESEARCH ON MATHEMAGENIC BEHAVIOR: IMPLICATIONS FOR TEACHING AND LEARNING SCIENCE

by

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INTRODUCTION

Written materials are convenient, easily produced and managed instructional stimuli which increasingly form the basis of instruction in science classrooms and science teacher education programs. Most science curriculum projects have produced large quantities of written materials for both learners and teachers. Textbooks, pamphlets, laboratory manuals and equipment, teacher's guides, programmed instruction, multi-media materials, and case studies are all used widely with all types of science students under all kinds of conditions. Specific materials are commonly selected for science classrooms because the knowledge presented in the materials coincides with some set of instructional objectives. Attention is rarely given to the complexity of the learning behavior implicit in acquiring the instructional content of the materials. In fact, many of the materials have been constructed with little thought as to how scientific knowledge and ideas are acquired, or what specific variations facilitate acquisition, or even how variations could be built into materials in order to maximize learning. Hence, it is not unusual that materials from a science curriculum fail to produce the expected effects in regular classroom settings [1]; many astute teacher has found it necessary to make extensive revisions. Neither revisions, reconstructions, or yet impending materials will be able to promote higher levels of success in terms of learner performance unless attention is first given to the potential that written materials have to influence learning behavior. Research on mathemagenic behavior is concerned with this relationship and hence relevant to the teaching and learning of science.

Science materials can influence the learning activity by presenting selected information in a fashion believed to be compatable with some notions of acquisition. When learning is assumed to accumulate in a progression from simpler, prerequisite levels to more complex levels, content should be arranged hierarchially[2]. Curricula such as E.S.C.P. and B.S.C.S. present information in sequences congruent with structures within the science discipline. While these sequences satisfy scholars, they are not superior in their ability to facilitate learning [3]. Other curricula such as <u>Science - A Process Approach</u> sequence their materials according to process based hierarchies. These hierarchies, however, are limited to the content of the hierarchy and cannot be generalized to new content without empirical validation[4]. Other science materials such as I.S.C.S. utilize programmed instruction where selected, sequenced, or repeated exposures are used to control acquisition. Here practice and other aspects of the learning activity are divided into relatively small discrete events by instructional components including presentation, practice, feedback, and reinforcement. [5] All of these approaches to constructing written science materials focus only on the relationships between presented stimuli and resulting observable performances, neglecting many possible ways in which learners respond internally. Short segments of programmed instruction seem to control the variance of acquisition among learners, but they also may limit the range of internal learner responses. This possibility illuminates why more complex learning tasks, which are considered to be dependent upon a wider range of internal responses, are perhaps not suitable as content for either highly segmented or hierarchial instruction.

Further consideration must be given to the possibility that the internal responses learners perform during instruction are educationally important and manageable. In addition, tactics for managing these internal activities may be more generalizable across content tasks than hypothetical hierarchies.

A plausible alternative approach to maximize learning is suggested by Ausubel [6] in his work on advance organizers. He proposes that meaningful learning occurs when the internal processes of the learner associate new information with subsuming concepts already in their cognitive structure. If suitable subsuming concepts do not exist in the learner's cognitive structure prior to instruction, the concept can be presented in advance of the new information as an "advance organizer". The effectiveness of "advance organizers" has been empirically demonstrated. [7,8,9].

Alternatives like Ausubel's advance organizers attempt to identify the internal responses learners make during instruction, explore the nature of these responses, and devise methods for managing them. Here internal responses are considered to be sensitive to external factors in that they can be directed or shaped by the placement of cues and prompts, such as questions, directions, diagrams, and examples, within written material or oral dialogue. Hence, material construction can utilize cues and prompts to influence these internal responses in a manner appropriate to attaining instructional objectives. For example, these mechanisms may be selected to direct the learner into the vicinity of the instructional material [10] , or guide his selecting and processing of appropriate instructional content [11], and possibly even shape his selection and processing of appropriate stimulus components [12,13,14]. All of the learner's responses, such as orienting, selecting, and processing, are activities classified as mathemagenic behavior.

Definition of Mathemagenic Behavior

The term mathemagenic was introduced by Rothkopf and derived from two Greek roots, Mathema, which means "that which is learned" and gignesthai, which means "to be born". Roughly translated mathemagenic behaviors are activities which give birth to learning [15]. During instruction these are the activities learners perform when confronted with instructional stimuli and hence they are the behaviors which give birth to learning.

In order to describe the relationship between mathemagenic behavior and how humans learn from written materials, a distinction must be made between the physical stimulus presented to the learner and the effective stimulus encoded by the learner [16]. The implication of this distinction is that the physical stimulus is not in simple correspondence to the encoded effective stimulus. The gap that probably exists could be attributed to differential orientation of attention, information processing of the physical stimulus, and the like. Since the effective stimuli are the basis for all subsequent learning activity, their character determines what is learned [17]. The notions of effective stimuli need not ~~be~~ limited to written stimuli, but may be extended to oral stimuli, or verbalization on the part of the learner as a result of a teacher behavior in an interactive situation which leads to learning.

When learning from written materials, learners must perform many mathemagenic activities collectively identified as reading. The mathemagenic activities performed can be both observable or hypothetical in nature. Observable activities include orienting activities which direct learners into the vicinity of instructional objects and stimuli, keep them there for suitable time periods, and select and procure appropriate instructional objects once in the vicinity [18]. Hypothetical activities may also be performed and are, in general, of greater interest to research in view of their potential to facilitate learning.

Three groups of hypothetical mathemagenic behaviors are: translation, segmentation and processing. During translation learners scan the written page and translate the alphabetic display into the sound of words or their subvocal surrogates. This process precedes encoding, and if the material is too difficult a result may be disorientation, an observable mathemagenic activity leading away from the instructional goal. Segmentation occurs when the learner breaks down stimulus strings into syntactic and other unit components [19]. The procedure attempts to account for the formulation of meaningful associative units within sentences as well as the more complex units associated between sentences. Finally, processing includes the variety of mental activities learners perform with information such as reviewing, categorizing, elaborating, devising mnemonic associations, and other information processing activities [20]. These activities function to elaborate ways learners can incorporate prior learnings into otherwise unfamiliar written stimuli. They may account for some of the variance between individual performances resulting from exposure to identical stimuli. Research in each of the aforementioned areas makes the assumption that these activities are persistent, topographical, exhibit rate characteristics, and are modifiable by certain environmental events.

In order for mathemagenic hypotheses to become functional, ways to influence learning behaviors must be identified. Since these behaviors are basically sensitive to elements within the physical stimulus, variations within this stimulus can be incorporated which exert influence upon selected mathemagenic behavior. In this sense, the physical stimulus can be designed to include prompts and cues that shape the mathemagenic behavior. The success of their influence upon specific mathemagenic activity follows the notion that the behaviors can be shaped. However, implicit in this notion is that the learner responds in a manner guided by stimuli and reinforced by the success of his generating suitable responses. Certain cuing or prompting techniques can be associated with each behavior identified above. Segmentation may be influenced by sentence order and relational wordage, including verb selection, tense, or proximity of key parts within the sentence [21]. Translation may be influenced by exposing learners to audio models of stimulus strings or underlying groups of words that receive special emphasis by influenced by directions, test like events, and other cues which direct attention or review activity toward important classes of information within the reading activity.

Research on the Control of Mathemagenic Activity

Interest in mathemagenic activity grew out of the use of questions within frames of programmed materials. Variations in question placement, frequency of questionning, and predictability of response were found to influence performance in terms of acquisition and retention of information [22]. The possibilit exists that the practice and repetition resulting from answering content loaded questions can directly influence acquisition. These direct instructional effects have been reported by many studies [23,24,25,26,27,28]. However, differences in acquisition occurring when only question placement was varied indicates that the mathemagenic activity may also be influenced. Studies of mathemagenic activity and factors that influence them may ultimately describe, from a generalizable perspective, ways to facilitate learning.

Directions are one type of instructional factor which seems to influence mathemagenic activities. Generally, research with directions have dealt with either directions of intent or manipulative directions for influencing search activity. The following are some specific research findings concerning directions;

- Postman and Sanders [29]. Directions to learn specific classes of information from text materials may influence learning; facilitation is not always in keeping with the intent of the directions.

Bruning [30], Rothkopf [31], Tenenberg [32]. Vague oratory directions of intent affect learner's mathemagenic activity associated with reading sufficiently to evaluate post test performance.

Frase [33]. Specific directions to find certain items of information in a test can also influence incidental learning in addition to the direct acquisition of relevant items.

Variation in sentence order and repetition of information have been found to alter inspection behavior, a mathemagenic activity associated with reading. The following are some specific research findings concerning this observation:

Rothkopf and Coke [34]. When passages provided immediate repetition of sentences containing key attributive information, poor retention resulted even when the phrasing of the repeated sentence had been changed upon repetition.

Generally, studies using questions are incidental learning studies where performances are measured on a second set of questions similar to the experimental questions. The experimental questions, often referred to as adjunct questions, are those placed at various locations within the instructional text material itself. However, the information necessary to answer the second set of questions, usually included on a post-test with the experimental questions, is identified as information incidental to the experimental questions. Hence, if a mathemagenic activity, such as inspection behavior, has been influenced positively, the subjects receiving the experimental questions inserted into the instructional material ought to acquire more incidental information than those subjects who do not receive the experimental questions. In this manner, any measured change between groups cannot be attributed to direct instructional effects of the experimental question's content.

An important characteristic of questions is their position in the text relative to the intended content. Ample evidence is available to support the findings that a simple change in position can radically transform consequent behaviors associated with reading. The following are some specific research findings concerning position of inserted questions:

Bruning [36]; Frase [37,38]; Rothkopf [39]; Rothkopf and and Bisbicos [40]. Experimental questions administered after inspecting text segments to which they are relevant produce significant gains in incidental learning.

Frase [41]; Rothkopf [42]. Questions when placed before relevant text material were found to provide significant depressing effects on acquisition of incidental learning.

Frase[43,44]. As the purpose of questions placed after the relevant segments of readings increased, acquisition of both incidental and intended information increased.

Questions asked in school learning situations elicit simple to complex responses. However, taxonomies currently in popular use lack the precision needed in order to identify or specify these levels of response [45]. Therefore, most experimental research which varies the type or categroy of question has required each researcher to operationally define levels of response. These are some of the specific findings in this area.

Rothkopf and Bisbicos [46]. Questions were defined in terms of eliciting definitions of common or technical terms. Groups expanded to inserted questions with technical terms had higher recall of other technical series.

Frase [47]. Questions were defined as comparative, specific, or general and all were rated by the learner according to the amount of information within the written passages, corrected to be relevant to answering the question. Ratings indicated that the number of words prescribed as necessary to answer questions increased in order to specific questions, comparative questions, and the general questions.

Frase [48]. The acquisition of intended and incidental information was found to be a function of level of complexity of question, here, less learning occurred with general questions than comparative questions with the most occurring with specific questions.

Watts and Anderson [49]. Subjects given higher order questions (application) versus recall and comprehension performed better on all categories of post-test questions.

The relationship between question type and the amount of similar information is also an important consideration. If the phrase contains little information of a nature similar to the type of response required, then the response becomes highly predictable, influencing inspection behavior to seek out only a few items of information. Specific research findings include the following:

Rothkopf [50]; Watts and Anderson [51]. Subjects given highly predictable response questions recalled significantly less incidental information than subjects whose responses were less predictable.

The learning resulting from inserted questions can also be associated with various individual learner characteristics. Here, findings support the notion that instructional variables such as the pacing of questions can enable learners to capitalize on various learning characteristics and aptitudes. Specific research findings here include the following:

Koran, M.L. and Koran, J.J. Jr. [52]. Measures of learner associative memory abilities were positively related to performance when subjects received inserted questions, but unrelated when they received no inserted questions.

> Wilson [53]. Measures of learner associative memory abilities were positively related to performance when subjects received inserted questions based on textual information, but not when inserted questions were based on diagrammatic information, or when questions were not inserted.

It has been assumed that questions influence behavior subsequent to the inserted questions, a process identified as forward shaping. However, questions may also serve to influence the learner to mentally review the information he considered relevant. The following research considers this alternative explanation:

> Watts and Anderson [54]. "Forward shaping" theories - behaviors subsequent to inserted questions are modified. "Backward review" behaviors are utilized after exposure to materials as with post questions.

The effects of inserted questions in written passages provides a means to contrast acquisition of intended and incidental learning. Here, success in answering the intended inserted questions is directly related to and the performance on the incidental, post-test questions. Specific research findings include the following:

> Wilson [55]. Answering inserted questions about diagrams was found to be positively related to acquisition of incidental diagrammatic information; a positive, but weaker relationship was found also between inserted textual questions and acquisition of incidental diagrammatic information.

Wilson's research is consistent with the notion that an additional multiplier is involved when considering the relative facilitative effects of inserted questions upon intended versus incidental learning.* This multiplier refers to the fact that the intended information, as measured by the intended post-test questions, represents a limited

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*E.Z. Rothkopf, personal communication

sample of content while the incidental information, represents a much larger sized universe of content. Subjects in the treatment groups with the intended inserted questions are cued to the information necessary for acquisition in order to produce better post-test performances. Therefore, they can attend to less information than subjects in other treatments would have to consider in order to achieve the same post-test performance. As a result, it is hard to tell how powerful the influence of inserted questions really is on these two performances, even when the post-test questions are the same.

Application of Mathemagenic Research and Theory to Science Instruction

Discussions of science instruction must not be limited to a narrow view confined to identifying content, specific techniques and demonstrations, and "necessary" prerequisites. While these variables have monopolized a great portion of concern in science instruction, they alone account for very little of the instructional differences in instructional effectiveness. Beyond these factors, mathemagenic research has established that different instructional sequences, patterns of questionning, material modes, and other instructional techniques are not equally effective in terms of facilitating learning. Research implications (see Berliner and Cahen [56]) suggest that a pattern of instruction may actually limit student achievement, a phenomena sometimes referred to as a "ceiling effect". Some of the implications of mathemagenic research will help identify which modes and patterns of instruction produce limiting effects on learning. Those which foster facilitative effects can in turn be incorporated into emerging notions of instruction which guide many current efforts to redesign science instruction and curricular materials.

Rothkopf [57] suggests the following generalizations about instruction, based on the foregoing research and theory.

1) "One way of fostering effective mathemagenic activities is to make sure the student knows what he is supposed to learn."
2) "Providing students with very explicit descriptions of what they are supposed to learn has powerful pedagogical impact."
3) "Students that are required to draw inferences from the instructional materials through use of questions or exercises, and are stimulated to go in other ways beyond the information given, have been found to remember more and are able to apply their knowledge in a greater variety of circumstances."
4) "Active participation through questions and other similar instructional devices is of particular importance for students who are having difficulty, or whose study efficiency is deteriorating."
5) "Creating and maintaining appropriate motivational states is not sufficient for learning success although this is frequently claimed in the apologetics of instructional failures. Experimental evidence suggests strongly that the student's intention to learn is neither sufficient nor

in many circumstances even necessary for achievement of instructional goals even in self-instructional situations. Learning has been shown to depend on fairly specific activities by the students which are not necessarily brought about by simply motivating the student's desire to learn."

6) "An effective instructional environment supports not only positive attitude towards the improvement of skills, but induces and maintains the intellectual maneuvers that aid in the desired learning and result in useful symbolic representations in the students memory."

Instructional Materials and Methods

Four general phases of instruction can be identified which prove to be useful in integrating mathemagenic research with instruction in science. These phases are (1) acquisition, (2) performance, (3) practice-retention, (4) transfer-generalizability. Acquisition refers to activities involving initial encounters with content followed by a performance situation where the student demonstrates what he has acquired. Practice includes activities where additional encounters with the content occur providing a means to increase levels of acquisition. Transfer activities generally focus the utilizing from an application of the content to new contents.

Considering first Rothkopf's general suggestions; focusing student attention on what is to be learned does not need to preclude particular school objectives for instance science objectives such as exploration, inquiry or the like. Rather these would occur at times when the learner has been prepared for them. In curricula such as Science-A Process Approach, SCIS and ESS major objectives are to stimulate process activities and conceptual and process acquisition. In the above model focusing would occur during the acquisition of skills stage, subsequently students could demonstrate the knowledge and skills acquired, practice them, diverge from them, and enter into exploration of new phenomena while using them. A similar interpretation could be extended to upper grade levels of science instruction only greater emphasis would probably occur in the performance, practice and transfer categories, assuming some prior knowledge.

In all of the above phases, as in all phases of instruction, active participation appears essential. Students must attend to instructional materials and to interactive instructional methods. Again, in science a pre-lab (Chem study, ESCP) or a single concept film (BSCS), case studies or programmed materials (project physics) and excursions (ISCS) challenge the teachers to elicit active participation. To foster this in the classroom context, activity oriented laboratories, questioning, responding to external stimuli, such as data collection, collating and interpretation are all worthwhile methods. However, before these occur one must be sure that minimal acquisition of skills has occurred and a demonstration of their acquisition (perfotmance) recorded. The classroom environment can be arranged for each of these.

School texbooks for the most part are constructed in such a way that they provide ample opportunity for teacher intervention in attempts to capitalize on mathemagenic behavior. For one thing, even though important terminology is highlighted, teachers may need to ask questions, derive relationships, and discuss meanings. Students should be taught that the highlighting has an instructional function. Similarly, ample diagrams and examples can be found in texts such as science, social studies, and others. Again, in order for these to become effective stimuli students must be directed to them, attend to them, and at least covertly respond to them. Finally, questions at the end of each chapter can be used as backward review components if students are directed to the releyant aspects of these questions. The teacher's job here is to stimulate mental review and processing through discussion, student-student interaction and the like.

The emphasis of mathemagenic research is on facilitating the translation of physical stimuli to effective stimuli. The mechanisms suggested generally imply structure: cues and prompts, questions, directions, diagrams, examples, directions, objectives, reviewing, categorizing and elaborating. These appear to have implications for how a classroom should be run — or what the environment or climate should be like. Open classrooms, classrooms without walls, and overly flexible and unstructured environments would seem to be the least appropriate settings for educating the average student. It has, however, been generally shown in learning research that low to average students require more structure than above average students.

Structure is also reflected in almost all school curricula presently in use in that students are required to read, if only directions, encode and perform. The classroom environment needs to be sufficiently controlled so that average students have the best opportunity possible to succeed. For instance, personal observation of supposedly "self-paced" programs in science classes suggests a tremendous burden on student reading skills as they work "independently" through workbooks. Most students do not have these skills adequately developed. Open envrionments only magnify the problems and reduce the teacher's opportunity to stimulate mathemagenic behaviors that might optimize the output from reading.

In conclusion, this has been an all too brief attempt to relate research, theory and practice. Gross generalizations are never wise because someone can always be counted upon to present a personal experience contrary to research findings, theory, and the authors' experiences. However, for the sake of discussion and professional stimulation, areas have been presented and discussed, here for which there are arguments pro and con. Whoever is correct, it must be kept in mind that the objective of instruction is learning and the purpose of schools is to provide a setting in which this can take place. Methods, materials and teachers should be selected for their ability to bring about learning. Although there may be many other noble goals or objectives ascribed to the schools, these authors will be satisfied if we achieve the purpose of producing and facilitating learning.

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