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AUTHOR Sambs, Hermann
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ABSTRACT

Considering the requisite skills and comparing commonalities in historical development, the disciplines of physics and mathematics can be viewed as related to and supportive of each other, yet it remains a curiosity that few, if any, cross-connections exist between school physics and school mathematics in the area of research on problem solving. This study synthesizes the up-to-date information available from research reports, books, and monographs with the intent of providing a base for interdisciplinary research on the comparison of problem solving in school physics and mathematics and for the promulgation of informed pedagogical considerations concerning the teaching of problem solving within these related fields at the middle school and high school levels. The studies reported here are organized into three groups as they relate to problem solving as both a general and specific activity, to the learner and his/her association with problem solving, and to the teaching of problem solving. A list of 66 references is included. (JJK)

Problem Solving in Physics and Mathematics--What Do They Have in Common? (Creating a Base for Research and Teaching)

Hermann Sambs

Department of Science Education

212 Aderhold Hall

The University of Georgia

Athens, GA 30602

(404) 542-1763

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Abstract

Problem Solving in Physics and Mathematics - What Do They Have in Common? (Creating a Base for Research and Teaching)

Problem solving in schools has been an important issue over decades. Research on problem solving has, however, always had certain limitations. It was mainly focussed on either the psychology of learning and teaching in general, or on one subject area such as mathematics, physics, chemistry or biology. However, because the natural sciences, and physics in particular, have been related to mathematics in their historical development and in some of their essential skills, and because in some schools these subjects are taught by the same teacher, possible commonalities in the domain of problem solving shall be explored.

This study synthesizes the information available to date. It intends to provide a base for interdisciplinary research on the comparison of problem solving in physics and mathematics and for informed teaching of problem solving in these related fields at the middle and high school levels. Reviewing the body of published literature in the categories of research reports, as well as books, monographs, and practical suggestions, shall help to give an overview of this interdisciplinary field of research in science education.

The studies reported here are organized into groups as they relate to (a) problem solving as an activity (general, mathematical, and physical problem solving), (b) the learner and problem solving, and (c) the teaching of problem solving.

Problem Solving in Physics and Mathematics - What Do They Have in Common? (Creating a Base for Research and Teaching)

Purpose and Significance of the Study

Problem solving has been a frequently discussed topic in the teaching of mathematics, physics, and other subjects in the field of science. Research on problem solving was, however, limited to the psychology of learning and teaching in general or, when more closely related to science education, also focussed on the subject areas of mathematics, physics, chemistry, biology, or engineering respectively.

For a teacher of several subjects of that group it can be particularly interesting to know whether or not it is advisable to use the same problem solving strategies in two subjects like mathematics and physics. In other countries, for example in Austria, it is a very common combination for a middle or high school teacher to be certified for teaching mathematics, as well as physics and chemistry - with major emphasis on one or two of these subjects. But it is more than just a personal or local aspect when a teacher or a researcher is interested in and concerned with a combination of these fields. Physics and mathematics can be seen as related to and supportive of each other when considering the kind of skills required and when comparing the historical development of these sciences. Therefore it is a surprise that in research on problem solving hardly any cross connections can be found between problem solving in mathematics and in science.

Defining the Field of Study

A lack of generally usable definitions of "problem" may at first appear to be an obstacle in setting limits to this study's field of investigation. However, it can be helpful to remember that teaching is also seen as an art (Gage, 1978). In an artistic domain then the quality of work can usually still be recognized to a fair extent, even when it may be difficult to find the right boundaries of quality. To set limits to this study it is necessary to find central fields, commonly accepted as being in close connection with problem solving. Ideas and suggestions from fields less central to the interest in a particular problem solving context can be included in the course of study as a welcome enrichment and a stimulation.

In order to compare a wide range of constructs used in problem solving research, studies concentrating on the areas of chemistry and biology were included in this synthesis. The age range studied with regard to the teaching of problem solving has been from ten to about twenty, or from the late elementary to the undergraduate years.

Some limits to the field of study have also been set in terms of problem solving context and content. Applications of problem solving to physics- and mathematics-related questions that address social and societal issues have not been in the focus of this study. Presumably a different set of constructs would have to be used for categorizing those problems and their solution processes. Another limitation has been made necessary by the flood of publications concerning the various ways of using computers in education. Only some studies were included that related the use of computers to problem solving or the teaching of a subject.

Discussion - An Overview of Problem Solving

1. Problem Solving As An Activity

a) General Problem Solving

Hayes (1981) writes that "Whenever there is a gap between where you are now and where you want to be, and you don't know how to find a way to cross the gap, you have a problem." He also names the two major parts of the process of finding a solution: "1.Representing the gap; 2.Searching to cross it" (p.5). A characteristic sequence of actions for the progress towards achieving a solution of a problem is described there (p.1) as follows: "1. Finding the problem. 2. Representing the problem. 3. Planning the solution. 4. Carrying out the plan. 5. Evaluating the solution (How good is the result?). 6. Consolidating gains (learning from the experience of problem solving)." Hayes also points out the difference between a diversity of internal representations of a problem in the solver's imagination and external representations such as drawing or writing. These ways of representation vary strongly among individuals and influence the solution process and success in solving a specific problem.

b) Problem Solving in Mathematics

An overview of the history of problem solving in teaching and learning mathematics is given by Burton (1979, pp.7-14). The work of Poincare, and especially that of Polya (1957) are identified there for their outstanding contributions to our knowledge of mathematical problem solving. Burton discerns five distinct groups of investigators: 1. Mathematicians concerned with the process aspects of mathematics in order to refine methods to teach heuristics; 2. A growing number of non-mathematicians, predominantly scientists, but also experts from business management, nursing education, and many engineers at the university level; 3. Philosophers such as Popper, Lakatos and Kuhn, as well as political scientists; 4. Psychologists who have entered the field of creativity and are interested in content-free training in problem solving, and 5. Mathematics educators.

In a class at Miami University taught by professors David Kullman and Jerry K. Stonewater, teachers were trained in mathematical problem solving and its implementation into classroom work. Six strategies were used when solving mathematical problems: 1. Guess and check; 2. Work backwards; 3. Elimination; 4. Simulation; 5. Simpler problem, and 6. Patterns. So there is helpful activity going on in mathematical problem solving. Similar progress toward some maturation of the field of problem solving in physics and the emergence of some easy to follow steps for teaching physical problem solving could be helpful.

c) Problem Solving in Physics

Padilla and Padilla (1986) give a historical perspective of stressing the ability to think as a major goal of science education. They describe science teaching in the early part of the twentieth century as influenced by the movement to establish the scientific method in school science teaching. But this method was seen as a rigid set of procedural steps and fell into disfavor. In the mid-century terms such as "problem solving" or "inquiry' became popular and represented a more fluid conceptualization of thinking in science. Terms like "critical thinking", "productive thinking", and "scientific thinking" were used for one or another aspect of the scientific method. For the period since the late sixties the term "science process skills" is given to characterize the aspect of thinking skills in science education. These skills are described as helping students in the science classroom to learn to formulate and verify hypotheses, to interpret data, to generalize, and they enable students to use these skills in other school and real life situations.

An approach frequently used in research in physics and mathematics teaching is the method of comparing the procedures used by novice and expert problem solvers. Chi, Feltovich, and Glaser (1981) used this method. They found that the knowledge of novice problem solvers is organized around a problem's literal features, whereas experts approach problem solving by initially abstracting the physics principles involved. Another approach is to compare good and poor novice problem solvers. De Jong and Ferguson-Hessler (1986) conclude that an organization of knowledge around problem types might be highly conducive to success in problem solving.

2. The Learner and Problem Solving

To focus on the learner's cognitive style as one kind of individual difference that effects problem solving performance is the goal of Ronning and McCurdy (1982). They criticize the emphasis on general knowledge and general problem solving methods as being incomplete models of learning problem solving. From the components of cognitive style they selected Witkin's concept of field-independence/field-dependence for their study. After a review of literature Garret (1986) resumes that no strong significant relationships exist between this cognitive style and problem solving, unless for highly field-independent students. While correlations between problem solving and intelligence are reported to be only moderate to weak (Vernon, 1988, Garrett,1986) that may have to do with the types of tasks assigned (e.g. Tower of Hanoi).

3. Teaching Problem Solving

In addition to differences in problem solving due to idiosyncrasies of the solver and to variables such as problem context (practical versus paper and pencil, group versus pair or individual solution, etc.) and problem content there is also the person of the teacher. Personal background of personality, formal education, intentions, a preferred teaching style, and experience in teaching and problem solving influence learning in the classroom. So far studies have not focussed on relationships between these factors and problem solving.

The teaching of general problem solving strategies is advocated by Adams (1986), who writes that attention must be paid to (a) general strategies, (b) specific skills, and (c) metacognitive abilities such as self monitoring and self regulation. The inexperienced student should learn activities such as identifying relevant elements in the available information and finding new information if necessary. De Bono (1983) even suggests to establish thinking as a subject in its own right because students' attention focuses on the subject discussed and not on the metacognitive level, and transfer then hardly occurs. Karmos and Karmos (1986) also cite the issue of lack of transfer and argue that not enough diverse kinds of problems are given to students to encourage transfer over a wider range of settings. Emphasis on a need for both general problem solving skills and specific knowledge is expressed by Bransford, Sherwood, Vye, and Rieser (1986)..

The role of computers for enhancing problem solving skills is discussed by several authors (e.g. Good, 1987, Lippert, 1987, McCoy, 1990, Rivers and Vockel, 1987). The flood of publications on and the wide range of applications of instructional use of computers as they relate to problem solving makes it impossible to thoroughly discus that facet of problem solving in this paper. A partial list of computer applications to problem solving could include: use of educational software to present problems, to teach or stimulate use of problem solving techniques, offering self-guided, self-paced coursework; use of computers as tools enabling the student to decide quickly about results of complicated computations, and in further consequence as an aid for simulations. Last but not least developing and testing computer programs written by students is also a procedure of problem solving that relates to mathematics and physics.

Finally an important suggestion for evaluating research on, teaching of, and student performance in problem solving comes from Isaacs (1987). He concludes that "It is possible that the average and below average students ... reverted to the restricted set of lower level thinking strategies under the strict examination rules which prevailed [in a particular examination situation studied]..." and that "... it might just be that it requires more than one year to modify the ingrained response styles of students".

Conclusions and Implications

It was not possible to find research that would explicitly explore differences between and common approaches of problem solving in mathematics and physics at middle school, high school or college levels. Therefore this paper is intended to serve as an orientation about the development of research on problem solving to the present. Information about the status quo in problem solving research and the way that led to that status shall help to learn from contrasting the approaches to problem solving taken in mathematics and physics. This study shall build a foundation for further research and shall finally enable the teacher to intentionally and professionally select the approach most appropriate for a given class of students and for a specific sequence of teaching that includes problem solving. The material studied also leads to the conclusion that although science as taught at the middle school grades integrates several academic disciplines, more interdisciplinary communication between researchers should occur. This includes a demand for intensified communication between educators and researchers of the underlying academic subject as well as among educational researchers of various subject areas.

While at this point a bibliography compiles sources of information, further analysis of the literature is necessary. This shall help to reveal common or specific dimensions of problem solving in physics and mathematics and contrast the problem solving research techniques used in these subjects.

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