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Artigo Científico

Piagetian and Neo-Piagetian variables in science problem solving: directions for practice

Variáveis Piagetianas e Neo-Piagetianas na solução de problemas científicos: direções empíricas

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Resumo

Este artigo apresenta uma visão global da investigação sobre variáveis piagetianas e neopiagetianas implicadas na solução de problemas, focando, ainda, como estas variáveis afetam a performance dos envolvidos na solução daqueles. Algumas das variáveis discutidas dizem respeito à habilidade formal de operacionalização: habilidade de razoamento formal, M-espaço, fator campo (dependência/ independência de campo), estilo cognitivo móbil/fixo, capacidade da memória de trabalho e colaboração nas tarefas de resolução de problemas. A partir da discussão efetuada, são sugeridas algumas recomendações para a melhora da instrução na resolução de problemas. © Cien. Cogn. 2008; Vol. 13 (2): xxx-xxx.

Palavras-chave: solução de problemas; variáveis cognitivas; variáveis Piagetianas; variáveis Neo-Piagetianas; medidas instrucionais.

Abstract

This paper presents an overview of research into Piagetian and Neo-Piagetian variables that are involved in problem solving and how these variables affect the performance of problem solvers. Some of the variables discussed are those of formal operational ability, M-space, field factor (field-dependence/field-independence), mobile/fixed cognitive style, working-memory capacity, and collaboration on problem-solving tasks. Based on the discussion, directions for the enhancement of instruction in problem solving are suggested. © Cien. Cogn. 2008; Vol. 13 (2): xxx-xxx.

***Key Words**: problem solving; cognitive variables; Piagetian variables; Neo-Piagetian variables; instructional measures.*

1. Introduction

Problem solving plays a very important role in science education. Solving science problems is an important topic at schools because they are used to train children to apply the scientific knowledge and skills learned. Besides, science problems are thought of as vehicle for developing students' general problem solving capacity and for making the science lessons more pleasant and motivating. Students often do not succeed in applying knowledge which the have acquired in lessons to given in school or every day contexts. This circumstance seems to apply especially to science lessons (Friege and Lind, 2006; Lorenzo, 2005; Solaz-Portolés and Sanjosé, 2006a, 2006b).

The past three decades have seen a great deal of studies in problem solving, and there is a growing consensus about mental processes and cognitive factors involved in science problem solving (Solaz-Portolés & Sanjosé, 2007a). The literature suggests that success in problem solving depends on a combination of strong domain knowledge, knowledge of problem solving strategies, and attitudinal components (Jonassen, 2000; 0'Neil & Schacter, 1999).

During the 1970s a great deal of attention has been given by Lawson and Karplus (1977), and Herron (1978) to the work of Piaget. These science educators pointed out that the major determinant of abstract concept achievement is students' formal reasoning. Neo-Piagetians Pascual-Leone and Goodman (1979) argued that formal reasoning alone cannot explain student success, and postulated a new model which provides explanatory constructs for cognitive development. On the other hand, according to Kubli (1989), Piaget's theory is misinterpreted as focusing on the subject and the environment without considering the social context.

The purpose of this paper is twofold: to present an overview of a number of Piagetian and Neo-Piagetian variables involved in problem solving in science, and how these variables mediate the performance of problem solvers; and to suggest some directions for classroom instruction to facilitate more effective problem solving.

2. Piaget and Neo-Piagetians and science problem solving

Jean Piaget is renowned for constructing a highly influential model of child development and learning. In Piaget's theory of the construction of knowledge, called the theory of genetic epistemology, logico-mathematical knowledge is progressively constructed by a child in interaction with a world . Piaget's theory is based on the idea that developing child builds cognitive structures or networked concepts for understanding and responding to physical experiences within his or her environment (Piaget, 1983). The construction of these structures is said to be explained by four factors: maturation, physical experience, social experience, and equilibration (or self-regulation) (Piaget, 1970). Maturation is defined as the growth of our brain, which opens up possibilities for the construction of structures. Equilibration was the term Piaget used to label the process of attempting to overcome conflict which leads to changes in cognitive structure. The importance of social experience is its impact on the equilibration process. Piaget proposed that cognitive conflict arising from social with other people can cause disequilibrium and thus learning to take place.

Piaget taught us that young children are fundamentally different kinds of thinkers and learners from adults –that they think in concrete terms, cannot represent concepts with structure of scientific concepts, are limited in their inferential apparatus, and so forth. His stage theory described several general reorganizations of the child's conceptual machinery –the shift from sensorimotor to representational thought, from pre-logical to early concrete logical thought, and finally to the formal thinking of adults. In Piaget's system, these shifts are domain independent (Carey, 1986). Developmental level is a Piagetian concept and refers to the ability of the subject to use formal reasoning (Lawson, 1985).

Most of the discussion of Piaget's work among science educators has focused on the transition between the concrete operational and formal operational stages and ways in which instruction can be revised in light of this model (Bodner, 1986). A great deal of attention has been given to the work of Piaget, pointing out that there may be a connection between age (maturity) and the complexity of thinking of which a learner is capable. Thus, Piaget's followers (Herron, 1978; Lawson and Karplus, 1977) argue that students who have not attained formal operational ability will not able to comprehend meaningfully abstract concepts and principles of science.

The Neo-Piagetian theory of Pascual-Leone provides explanatory constructs for cognitive development by postulating:

a) the M-operator or M-space, which accounts for an increase in students' information processing capacity with age (Pascual-Leone and Goodman, 1979);
b) the field factor (field-dependence/field -independence), which represents the ability of a subject to disembed information in a variety of complex and potentially misleading instructional context, thus, the learners that have more difficulty than others in separating *signal* from *noise* are classed as field-dependent (Pascual-Leone, 1989);
c) the mobile/fixed cognitive style, which arises from a combination of mental capacity (M-space) and disembedding ability, fixity characterizes consistency of function of field-independent subjects in a field-independent fashion, while mobility provides for variation according to circumstances (Pascual-Leone, 1989).

Psychological tests are research tools used more often to determine students level of reasoning and Neo-Piagetian variables.

Research on problem solving has shown that the psychometric variable working memory can be predictive, in certain cases, of student performance (Johnstone *et al.*, 1993; Niaz and Loggie, 1993; Tsaparlis *et al.*, 1998). Working memory has storage function and researchers use working memory capacity to represent the amount of information activated and retained while completing cognitive tasks (Yuan *et al.*, 2006). The capacity of working memory is limited, and the imposition of either excess storage or processing demands in the course of an on-going cognitive activity will lead to catastrophic loss of information from this temporary memory system. For the model developed by Brooks and Shell (2006) (Interactive Compensatory of Learning Model), *expertise* is thought of in terms of forming ever-larger knowledge *chunks*, and *ability* is related strongly to working memory capacity. Working memory capacity plays an important role in many different types of problem solving (Welsh *et al.*, 1999). The ability to maintain information in a highly activated state via controlled attention may be important for integrating information from successive problem-solving steps.

A characteristic model of science problem solving is the Johnstone –El Banna model (Johnstone and El-Banna, 1986). This model is based on working-memory theory as well as on Pascual-Leone's M-space theory. It states that a student is likely to be successful in solving a problem if the problem has a mental demand which is less than or equal to the subject's working-memory capacity, X (i.e., $Z \leq X$, the authors approximated the Z value to the number of steps in the solution of the problem for the least talented but ultimately successful students), but fail for lack of information or recall, and unsuccessful if $Z > X$, unless the student has strategies that enable him to reduce the value of Z to become less than X. Simple problems have been used to study the necessary conditions for the validity (Tsaparlis, 1998), as well as the operation and the validity itself (Tsaparlis and Angelopoulos, 2000) of the Johnstone-El-Banna model.

3. Effects of formal reasoning ability and Neo-Piagetian variables on students solving science problems.

Positive linear relationships between formal reasoning activity (developmental level) and achievement in science problem-solving have been described by a number of authors (Lawson, 1983; Chandran *et al.*, 1987; Níaz, 1987a; Zeitoun, 1989; Bunce and Huchinson, 1993; Tsaparlis *et al.* 1998, Demerouti *et al.*, 2004). More general studies by Staver and Halsted (1985) and by Robinson and Níaz (1991) also support this relationship.

In science, mental capacity (M-space) is associated with students' ability to deal with problem-solving (Níaz, 1987a; Tsaparlis *et al.*,1998; Tsaparlis, 2005). However, students with higher information processing capabilities (higher mental capacity scores) do not always perform better than students with lower mental capacity scores (Chandran *et al*., 1987; Robinson and Níaz, 1991).

Studies by Níaz (1987a), Tsaparlis (2005), Danili and Reid (2006), Tsaparlis and co-workers (1998), Johnstone and co-workers (1993), and by Demerouti and co-workers (2004) have indicated that students with better disembedding ability (i.e. field- independent students) are more successful solving problems than students with lower disembedding ability scores (*i.e.* field-dependent students). However, studies by Chandran and co-workers (1987), and by Robinson and Níaz (1991) have shown that this cognitive variable played no significant role in science achievement. Overall, the field dependent/independent test is considered by some researchers a very powerful instrument to predict academic performance of individuals (Tinajero & Paramo, 1998).

The results of various works (Níaz, 1987b; Níaz *et al*., 2000; Stamovlasis *et al*., 2002) support the hypothesis that mobility-fixity dimension can serve as a predictor variable of students' performance on problem-solving. Moreover, the most *mobile* students performed best on creativity tests whereas *fixed* students performed better on tests of formal reasoning (Níaz and Nuñez, 1991). Mobile subjects are those who have available to them a developmentally advanced mode of functioning (*i.e.*, field-independence) and a developmentally earlier mode (*i.e.*, field-dependence)(Níaz, 1987b).

Many researchers tended to equate divergent thinking with creativity and convergent thinking with intelligence. This has caused a great deal of controversy, with different research supporting different results (Bennett, 1973; Runco, 1986; Fryer, 1996). According to Hudson (1966) the *converger* is the student who is substantially better at intelligence test than he is at the open-ended tests; the *diverger* is the reverse. Convergent thinking demands close reasoning; divergent thinking demands fluency and flexibility (Child and Smithers, 1973). In the literature little research is reported on convergent/divergent cognitive styles and performance in science. In the work of Danili and Reid (2006) the convergent/divergent characteristic correlated with pupils' performance in assessment where language was an important factor, but not in algorithmic types of questions or in questions where there is a greater use of symbols and less use of words. In almost all the tests the divergent pupils outperformed convergent pupils and, when there were short answer or open-ended questions, the differences in the performance between the divergent and convergent groups became larger.

Studies on the association between limited working memory capacity and information load in problem-solving provided support for the positive relationship between working memory and science achievement. Gathercole (2004) found a strong relationship between working memory capacity and science achievement: the correlation coefficients between working memory measure and science achievement ranged from 0.32 to 0.5. Danili and Reid (2004) found that students with high and low working memory capacity differed significantly in their performance on chemistry tests. Tsaparlis (2005) examined the correlation between working memory capacity and performance on chemistry problem-solving and the correlations ranged between 0.28 and 0.74. Because working memory capacity limits the amount of information which can be concurrently processed, performance on science problem-solving tasks is expected to drop when the information load exceeds students' working memory capacity (Johnstone and El-Banna, 1986). Opdenacker and co-workers' (1990) study reported that students gradually decreased their chemistry problem-solving performances when the amount of information to be processed exceeds their working memory capacity. This phenomenon is also consistent with Sweller's (1994) cognitive overload theory, which posits that learning processes will be negatively affected if the cognitive load exceeds the limit of working memory capacity.

Years of research support that cooperative learning is an effective instructional strategy in classrooms. For example, researchers following the Piagetian tradition (Doise, 1986; Doise and Mugny, 1984; Doise and Palmonari, 1984) propose that collaboration on problem-solving tasks increases performance. Lumpe (1995) gathers results of several investigations that suggest the effectiveness of peer collaboration in science concept development and problem solving.

4. Directions for practice

Skill in problem solving depends on the effective interaction of cognitive variables such as those discussed above. Based on the overview on problem solving presented in this paper, a number of instructional measures that will assist teachers are suggested below.

- Teachers should utilize teaching methods that could make abstract concepts more accessible for students lacking formal operational abilities. In the main, these methods make use of concrete materials, e.g., models, pictures, illustration and diagrams to cross-fertilize the concrete conceptions with the abstract ones (Zeitoun, 1989).
- In order to cater for the needs of the low formal thinkers and those with less knowledge, science teachers should endeavor to engage students in individualized tasks, and in small group work so that all students have an equal opportunity to participate (Chandran *et al.*, 1987).
- Alloway (2006) suggests that the learning progress of students with poor working memory skills can be improved dramatically by reducing working memory demands in the classroom. She recommends a number of ways to minimise the memory-related failures in learning activities: by using the instructions that are as brief and simple as possible, by reducing the linguistic complexity of sentences, by breaking down the tasks into separate steps, by providing memory support, by developing in the students effective strategies for coping with situations in which they experience working memory failures, etc.
- It is useful for the teacher to know that you can change the M-demand (mental demand) of a item (problem) without changing its logical structure. Thus can facilitate student success by decreasing the amount of information required for processing, that is, avoiding working memory overload (Níaz, 1987a). We can facilitate student success by introducing first problems of low Z-demand, and leaving problems of high Z-demand for later use in the course, when students have acquired experience and motivation or have developed efficient strategies (Stamovlasis and Tsaparlis, 2005). Johnstone and co-workers (1993) give evidence that a physics problem can be presented in such a way as to reduce the noise input to the processing system, and as consequence to allow greater success for all students but particularly for the field-dependent students. According to these authors the form of a problem with words plus a diagram can be seen as a way of reducing memory overload.
- By providing goal-free problems to students, Sweller and co-workers (1998) argued that students only had to maintain the problem state and any problem-solving step applicable to that state and thus reduced the cognitive load.
- Provide students with diverse, continual and prolonged problem-solving experiences. Associated with all problems are three variables: the data provided, the method to be used and the goal to be reached (Johnstone, 1993). Once students have derived and understood procedures for basic problems (recall of algorithms), they should be given plenty of practice to the other problem types, for example, problems unfamiliar to the student that require, for their solution, more than conceptual knowledge application, analysis, and synthesis capabilities, as well as making connections and evaluative thinking on the part of the solver. Give practice of similar problem solving strategies across multiple contexts to encourage generalization.
- Science education literature indicates that using multiple representations is beneficial for student understanding of physics ideas and for problem solving (Solaz-Portolés and Sanjosé, 2007b). These representations can include but are not limited to words, diagrams, equations, graphs, and sketches. The hypothesis of Rosengrant and co-workers (2006) is that students are probably aware intuitively that they do not have the mental capacity to remember all the information in

the problem statement, and thus use the representations to visualize an abstract problem situation.
- The design of teaching strategies than can facilitate conceptual understanding (beyond the algorithmic strategies), plus the use of a variety of problems of variable logical structure and of demand for information processing, can provide a means for the development of various cognitive abilities (Tsaparlis and Zoller, 2003). One technique that can be used by teachers to help students organise their understanding of a topic is concept mapping (Pendley *et al.*, 1994). The introduction of a concept map can often assist students to understand the concepts and the relationships between them (Novak and Gowin, 1984).
- Group work should be designed to maximize sociocognitive functioning so that beneficial conflict can occur. Peer groups should consist of students who bring with them a variety of ideas and opinions. Heterogeneous grouping based on prior conceptions or problem solving ability will help enhance problem solving and concept development ability (Lumpe, 1995).

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