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Measuring students' progressions in scientific problem solving: A psychometric approach

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Abstract

The ability to solve complex problems is one of the key competencies in science. But until now, little research on students' progressions in scientific problem solving has been conducted. This study addresses the following research question: Which factors can be distinguished in order to describe the structure of the ability to solve scientific problems and how does this ability develop across grade levels? Within a cross-sectional survey, we used computer-based assessment tools to capture students' problem-solving abilities in grades 8, 10, and 12 (*N*=1,487). Based on four key dimensions, a vertical scale has been established by using an IRT modeling approach. This model was tested for measurement invariance as a prerequisite for comparing different grade levels and was, finally, validated by multilevel regression analyses. Our results showed that the ability to solve interactive scientific problems can be described by four cognitive factors. Based on a vertical scale, this structure held across grade levels and revealed significant progressions. Finally, different developmental patterns were found, which were related to reasoning, strategy knowledge, and domain knowledge. We conclude that our model of scientific problem solving can be used to capture students' interindividual progressions.

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Keywords: Computer-based assessments; Learning progressions; Scientific problem solving; Vertical scaling

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1. Introduction

1.1 Problem statement

The ability to solve complex scientific problems is regarded as one of the key competencies students should acquire during adolescence. There have been various approaches of modeling scientific problem solving, its structure, and implementation in science lessons (Klahr & Dunbar, 1988; Koppelt, 2011; Scherer & Tiemann, 2012). These approaches have shown that the cognitive processes, which are involved in a problem-solving process, are of major importance for the definition and operationalization of the construct, especially when using computer-based assessments (Funke, 2010; Wirth & Klieme, 2004). Surprisingly, few studies have examined the structure of problem-solving processes across grade levels. Especially during adolescence, little is known about students' learning progressions in scientific problem solving. But there is a need for models, which describe at least *inter*individual developments, as they allow researchers and educational practitioners to design meaningful and appropriate instructions (Köller & Parchmann, 2012).

This study systematically extends previous research on assessing and modeling problem solving. So far, the structure of the construct has only been investigated for small samples and without taking into account multi-group structures in data sets (e.g., Kröner, Plass, & Leutner, 2005; Wüstenberg, Greiff, & Funke, 2012). Furthermore, to our knowledge, there has been no study, aimed to compare students' performance across grade levels in science. The present study, thus, aims to close this gap by modeling a large-scale data set with multi-group approaches. We also address measurement concepts such as factorial invariance in order to overcome statistical shortcomings on how to compare different subsamples.

1.2 The present study

In light of the proposed research gaps, the present study aims to:

- describe the structure of scientific problem solving by using uni- and higher-dimensional models which are based on theoretical assumptions about cognitive processes.
- establish a vertical scale which can be used to compare students' performance in scientific problem solving across grade levels.

2. Theoretical background

As problem solving refers to bridging a gap between an initial and a goal state, different operationalizations are possible. For example, Funke (2010) and Wirth and Klieme (2004) proposed a framework which distinguishes between *analytical-static* and *complex-interactive* problem solving. In complex problem solving, the information which is necessary in order to successfully solve the task is not immediately given from the beginning of the problem solving process. Students must, therefore, interact with a given system or experiment and acquire knowledge about the system (Goode & Beckmann, 2010). The resulting knowledge enables them to bridge the gap between an initial and a goal state and, finally, solve the problem (Novick & Bassok, 2005; Wirth & Klieme, 2004). In contrast, analytical problem solving is strongly related to reasoning and requires tasks which contain all information necessary for a problem solution (Jonassen, 2011).

The cognitive processes which are involved in scientific problem solving have been described from different perspectives. For instance, Newell and Simon (1972) proposed a dual space model which assumed a problem space and a search space. In these spaces, internal and external processes occur (*DS model*, tab. 1). Klahr and Dunbar (1988) specified these processes and proposed three components (*SDDS model*, tab. 1). Finally, Koppelt (2011) combined previous models of domain-general problem solving (e.g., OECD, 2010) with chemistry-