Computers in Human Behavior 59 (2016) 446–455

Contents lists available at ScienceDirect

Computers in Human Behavior

journal homepage: www.elsevier.com/locate/comphumbeh

Model development in scientific discovery learning with a computer-based physics task

Saskia Kistner [a,*], Regina Vollmeyer [a], Bruce D. Burns [b], Ulrich Kortenkamp [c]

[a] Department of Psychology, Goethe-University, Theodor-W.-Adorno-Platz 6, D-60629 Frankfurt, Germany
[b] School of Psychology, University of Sydney, Brennan MacCallum Bldg, A18, Sydney, NSW, 2006 Australia
[c] Institute of Mathematics, University Potsdam, Am Neuen Palais 10, D-14469 Potsdam, Germany

ARTICLE INFO

Article history:
Received 19 May 2015
Received in revised form
12 January 2016
Accepted 9 February 2016
Available online xxx

Keywords:
Scientific discovery learning
Multiple problem spaces
Computer simulations
Physics concepts
Misconceptions
Conceptual change

ABSTRACT

Based on theories of scientific discovery learning (SDL) and conceptual change, this study explores students' preconceptions in the domain of torques in physics and the development of these conceptions while learning with a computer-based SDL task. As a framework we used a three-space theory of SDL and focused on model space, which is supposed to contain the current conceptualization/model of the learning domain, and on its change through hypothesis testing and experimenting. Three questions were addressed: (1) What are students' preconceptions of torques before learning about this domain? To do this a multiple-choice test for assessing students' models of torques was developed and given to secondary school students (N = 47) who learned about torques using computer simulations. (2) How do students' models of torques develop during SDL? Working with simulations led to replacement of some misconceptions with physically correct conceptions. (3) Are there differential patterns of model development and if so, how do they relate to students' use of the simulations? By analyzing individual differences in model development, we found that an intensive use of the simulations was associated with the acquisition of correct conceptions. Thus, the three-space theory provided a useful framework for understanding conceptual change in SDL.

1. Introduction

Students can learn the principles governing a domain of science through a process of *scientific discovery learning,* in which they perform experiments to discover the rules that underlie scientific principles (van Joolingen & de Jong, 1997). Research in the fields of conceptual change and mental models has addressed learners' conceptions of science domains and has shown that students often hold conceptions that either are not consistent with or in conflict with the scientific fact (e.g., Clement, 1982; McCloskey, 1983).

In this paper, a framework is introduced to describe development of scientific models in scientific discovery learning in terms of search of three spaces. Within the context of a three-space theory of learning (Burns & Vollmeyer, 2000; Kistner, Burns, Vollmeyer, & Kortenkamp, in press), we developed a measure for assessing students' models of torques. This measure was used in a study where students learned about torques using computer simulations. Students' preconceptions of torques and the change of these conceptions while learning with computer simulations are studied. Another major focus of this study is to explore the interaction between the three spaces predicted by the theory, that is, how conceptual changes correspond to simulation use.

1.1. Theories of scientific discovery learning

In scientific discovery learning, learners have to "find the properties of a given domain. These properties are not given directly, but have to be inferred or induced from other data" (van Joolingen & de Jong, 1997, p. 308). Learners do experiments in a predefined learning environment where they can test hypotheses about underlying rules that hold in the given domain, for example relations between variables. Often computer simulations are used as learning environments for scientific discovery learning (de Jong & van Joolingen, 1998). Here, principles of the domain to be studied are simulated and learners can manipulate variables and observe the effects of their manipulations with the goal to infer the underlying principles.

* Corresponding author.
E-mail addresses: kistner@paed.psych.uni-frankfurt.de (S. Kistner), bruce.burns@sydney.edu.au (B.D. Burns), ukortenk@uni-potsdam.de (U. Kortenkamp).

http://dx.doi.org/10.1016/j.chb.2016.02.041
0747-5632/

Theories of scientific discovery learning draw on its similarity to true scientific discovery, that is, the scientific reasoning processes that scientists perform while doing research. Referring to theories of problem solving (Newell & Simon, 1972; Simon & Lea, 1974), Klahr and Dunbar (1988) proposed the Scientific Discovery as Dual Search (SDDS) theory. They conceptualized scientific discovery as search of two interacting problem spaces, hypothesis space and experiment space. Hypothesis space contains possible hypotheses that can be stated concerning the current task, and experiment space contains possible experiments that can be run. The scientific discovery process involves three basic processes. In a first step, hypothesis space is searched to yield a specific hypothesis to be tested. Next, the hypothesis is tested by choosing and conducting experiments (movement in experiment space), and finally the outcomes are evaluated against the hypothesis. During the first process, search of hypothesis space, prior knowledge is regarded as an important source for generating new hypotheses and for judging hypotheses regarding their plausibility (Klahr, 2000).

An extension of the SDDS theory was presented by van Joolingen and de Jong (1997). While Klahr and Dunbar (1988) primary aim was to model the process of scientific reasoning, van Joolingen and de Jong directly focused on scientific discovery learning in complex domains. Therefore, they proposed a need to specify both the structure of the hypothesis and experiment spaces, and the search mechanisms for these spaces. They also consider the learner's domain knowledge by distinguishing subsets of hypothesis space. Whereas the *universal hypothesis space* contains all possible hypotheses, the *learner hypothesis space* is a subspace that is constrained by the variables and relations the learner is able to think of. A subspace of the latter is the *effective learner search space,* which consists of the hypotheses that the learner considers to be plausible and worthwhile to test. The learner's initial domain knowledge is crucial for defining these two subspaces. Besides prior knowledge, the additional knowledge of the domain acquired through the discovery learning process is taken into account within van Joolingen and de Jong's theoretical framework. Through scientific discovery learning emerges a space of supported hypotheses which contains the *target conceptual model.*

A similar extension of the SDDS theory proposed by Burns and Vollmeyer (2000) focuses on the question where hypotheses come from, or similarly, what defines hypothesis space. Here, not only is prior factual domain knowledge considered as a source for hypotheses, but also conceptualizations (models) of a domain that may or may not be appropriate. These conceptualization/models could have emerged, for example, from daily life experiences or have been developed in other domains and then applied to a new domain. To cover these concepts, a third space is introduced: model space. The postulation of a model space arose from empirical studies of dual space search with complex systems (Burns & Vollmeyer, 2002). Participants had to discover links between inputs and outputs in a linear system. Verbal protocols revealed that they started with very different hypotheses, representing different ideas of which kinds of links could be considered. For example, some participants considered that there might be interactions between variables, which was not the case. Thus, participants seemed to hold a certain conceptualization (or model) of the linear system, which determined the hypotheses they took into account and so defined hypothesis space.

In the three-space theory postulated by Burns and Vollmeyer (2000), model space is supposed to contain different conceptualizations/models of the given task or of the learning domain and the learners' actual state in model space represents their current conceptualization/model. The current state in model space constrains hypothesis space and determines the hypotheses to be tested. Search of hypothesis space interacts with search of experiment space, in which the hypotheses are tested. The evaluation of the experiments leads to confirmation or rejection of the hypotheses. This hypothesis testing process can in turn lead to movement in model space, which can take place to different degrees. Information obtained from the hypothesis testing could enrich or refine the model of the learning domain. On the other hand, if no progress is made with the tested hypotheses, then a greater movement to a completely different model via some kind of major conceptual change could be necessary. A graphical illustration of the three spaces and their assumed interrelations is shown in Fig. 1. Support for the three-space model was found in a study by Kistner et al. (in press) in which an interaction between a manipulation of model state and of goal state was hypothesized and supported.

In the following section we will link our research to existing theoretical approaches that deal with learning in the physics domain, especially conceptual change and mental models. In the three-space theory the term “model” is used in a similar way as the term “concept” is used in the conceptual change literature. To prevent unnecessary confusion we use the term “model” when we refer to the three-space theory and the term “concept” in the context of conceptual change research.

1.2. Concepts of physics domains

Research on conceptual change deals with changes in a learner's conceptual knowledge, which involves restructuring of this knowledge (Duit & Treagust, 2003). When new information conflicts with a learner's previous concept of a domain, conceptual change is required, that is, “a major reorganization of prior knowledge” (Vosniadou & Verschaffel, 2004, p. 445). In contrast to this knowledge-as-theory view (e.g., Chi, 1992; Vosniadou, 1994), in the knowledge-as-elements view (e.g., diSessa, Gillespie, & Esterly, 2004; Smith, diSessa, & Rochelle, 1993) conceptual change can also be described as refining or revising the organization of conceptual elements, for example through adding or eliminating elements. In the field of physics, conceptual change has been extensively studied and a lot of research has focused on students' concepts of physics domains that do not fit to the scientific reality (e.g., Chi & Slotta, 1993; diSessa & Sherin, 1998; Ioannides & Vosniadou, 2002; Özdemir & Clark, 2009; Sherin, 2001; Slotta, Chi, & Joram, 1995).

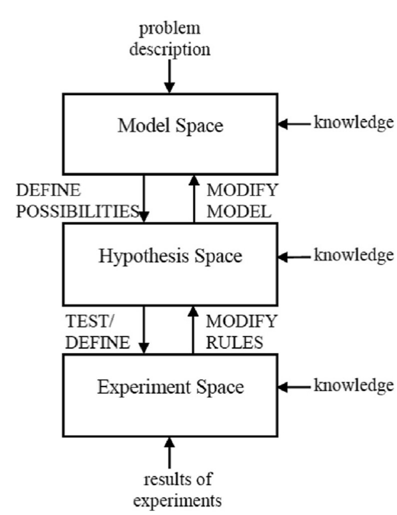

Fig. 1. The three-space-search theory of problem solving. Adapted from “Problem Solving: Phenomena in Search of a Thesis,” by B. D. Burns and R. Vollmeyer, 2000, in L. Gleitman & A. K. Joshi (Eds.), Proceedings of the twenty-second annual meeting of the cognitive science society (pp. 627–632). Hillsdale, NJ627632: Lawrence Erlbaum.