de Jong, T. & van Joolingen, W.
Scientific discovery learning with computer simulations of conceptual domains
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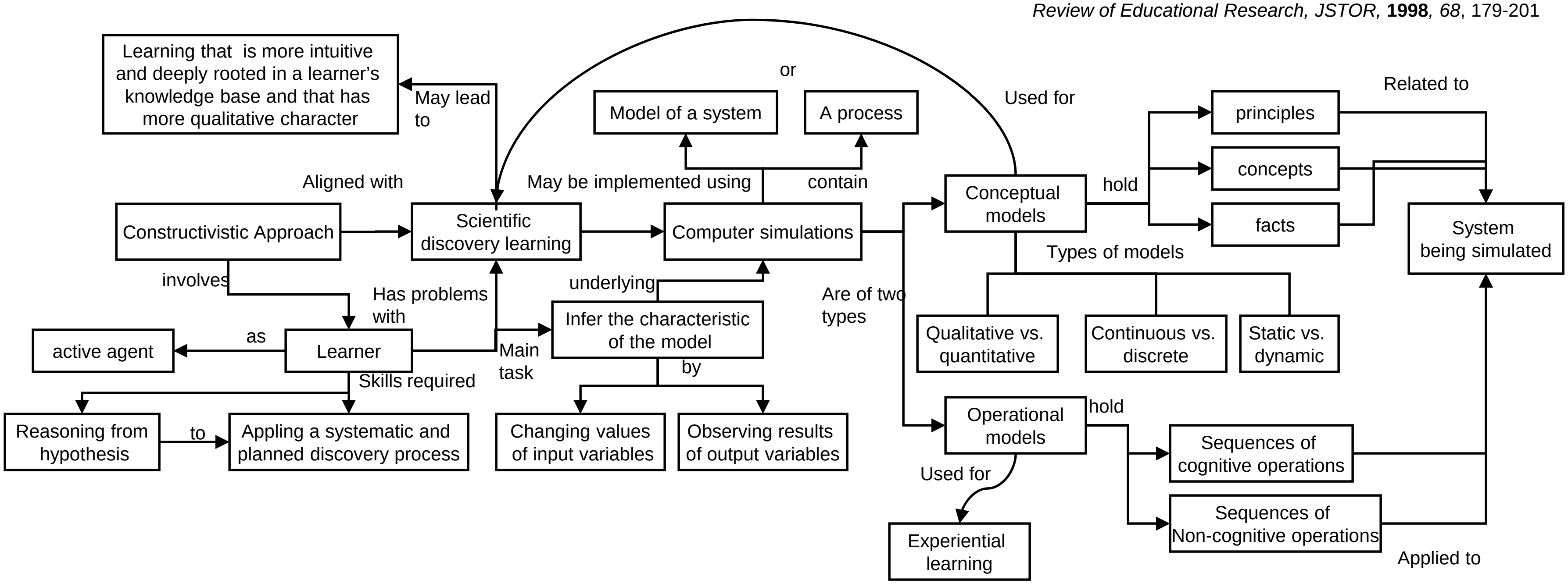

Theories of scientific discovery	
Authors	Theory
Rivers and Vockell (1987) P. 180	Described a cycle that involves the following steps: planning including activities such as designing and experiment, Executing including the process of carrying out the experiment and collecting data and evaluating involving analyzing the data and developing a hypothesis
Friedler, Nachmias, and Linn (1990, p 173) p. 180	Scientific reasoning comprises the following steps: Define the scientific problem Sate a hypothesis Design the experiment Observe, collect, analyze and interpret data Apply results Make predictions on the basis of the results
De Jong and Njoo (1992) p. 181	Identified two main categories: transformative processes involving processes that yield knowledge directly (e.g., hypothesis generation, execution of experiment, etc) Regulative processes such as planning and monitoring
Klahr and Dunbar () p.181	Proposed the theory of scientific discovery as dual search (SDDS). It considers two spaces: Hypothesis pace refers to search space consisting of all rules possibly describing the phenomena that can be observed within a domain Experiment space consists of experiments that can be performed with the domain as well as the outcomes of such experiments.

Overview of prior studies		
Authors	Domain and Instructional Method	Findings
Bangert-Drowns, Kulik and Kulik (1885) p. 181 Domain: varied (overview)	variety	Reported that simulation-based learning doses not raise examination scores
Grimes and Willey (1990) p. 181 Domain: economics	The curriculum or expository instruction as such	Reported favorable results
Carlsen and Andre (1992) p. 181 Domain: electrical circuits	Simulation embedded in a curriculum versus expository instruction	No difference between simulation-based learning and expository teaching
Rivers and Vockell (1987) p.181 Domain: biology	The curriculum or expository instruction as such	Reported a mixture of favorable and no-difference results
Rieber et al (1990) p. 181	Simulation versus simulation and tutorial Not simulation but tutorial and additional questions while learning versus simulation and tutorial.	The simulation and tutorial group performed higher on a test measuring application of rules. The tutorial plus learning performed as equal as the simulation and tutorial group
Rieber and Parmley (1995) p. 181 Domain: Newtonian mechanics	Unstructured pure simulation versus tutorial A single simulation versus expository instruction	The subjects who received only an structured (pure) simulation fell short of the performance of subjects who received a tutorial.
"The general conclusion that emerges from these studies is that there is no clear and univocal outcome on favor of simulations. An explanation of why simulation-based learning does not improve learning results can be found in the intrinsic problems that learner may have with discovery learning. (p.181)"		

Overview of problems identified	
Authors	General problem
Chambers et al. (1994) P. 182	Noticed that the students were unable to deal with unexpected results and that the students did not utilize all the experimenting possibilities that were available.
Friedler, Nachmias, and Linn (1990, p 173) p. 180	Scientific reasoning comprises the following steps: a) Define the scientific problem, b) sate a hypothesis, c) design the experiment d) Observe, collect, e) analyze and interpret data, f) apply results and g) make predictions on the basis of the results
De Jong and Njoo (1992) p. 181	Added a distinction between: transformative processes (processes that yield knowledge directly) and Regulative processes (for example planning and monitoring)
Klahr and Dunbar (1988) p.181	Proposed the theory of scientific discovery as dual search (SDDS). It considers two spaces: Hypothesis pace (is a search space consisting of all rules possibly describing the phenomena that can be observed within a domain) Experiment space (consists of experiments that can be performed with the domain and the outcomes of these experiments).
Thomas & Hooper (1991) Anderson & Lawton (1992) Flick (1990) McDermott (1990) Whitelock (1993) Leutner (1993) Mandl, Gruber and Renkl (1994) Rieber (1996) Rieber et al. (1996) Swaak et al. (1998)	The researchers showed that although simulations can be effective in teaching "the ability to acquire certain state in the simulation (Thomas & Hooper p. 193)", this did not mean that the same effectiveness has been acquired in a conceptual level. Or in other words students just acquired functional knowledge instead of a conceptual knowledge.

Problems related to hypothesis generation

<table>
<tr><th>Problem</th><th>Possible cause of the problem</th><th>Possible solution to the problem</th></tr>
<tr><td>Chinn & Brewer, 1993
The authors identified that students found coming up with new hypothesis as a difficult process. These authors also cite a large number of studies in which it was found that learners ignore anomalous data.</td><td rowspan="5">Schauble, Glaser, et al. 1991
Distinguished successful and unsuccessful learners by identifying several characteristics. One of them is that coming up with new hypotheses distinguishes the successful ones.
Glaser et al. 1992
Schauble, Glaser et al. 1991
The authors also identified insufficient prior knowledge as a potential reason of why learners do not know which hypothesis to state, cannot make a good interpretation of data, and engage in unsystematic experimentation.</td><td rowspan="5">Glaser, Ragahvan and Schauble 1988
Lajoie 1993
Thomas & Nielson 1995
Introduced access to extra information as a support measure in a simulation environment, quite often in the form of a hypertext/hypermedia system
Shute 1993
Introduced an intelligent tutoring system (ITS) on basic principles of electricity in which learners could ask for a definition of a concept by selecting a term from a menu and follow hypertext links.
Berry and Broadbent (1987)
Found that providing information at exactly the moment it is needed by the learner is much more effective than providing all necessary information before interaction with simulation begins.
Leutner (1993)
Gave students information (consisting of domain concepts, facts, rules and principles) before interacting with the simulation, whereas other students were given information (background information on system variables) while interacting with the simulation. Leutner found that permanently available information before the simulation was not effective.
Elshout and Veenman (1992)
Reported that subjects who received domain information before working in a simulation environment (on heat theory) did not profit from this information.
Lewis, Stern, and Lin (1993)
Information must not only be provided by the learning environment but also be invoked from learners' memory.
Provided learners with an electronic notation from for noting "everyday life examples" of phenomena they observed in a simulation environment (on thermodynamics).
Shute and Glaser (1990)
Offered the learners support for hypothesis generation by means of a hypothesis menu. This menu presents parts of a hypothesis such as variables, verbs to indicate change, and connectors
Van Joolingen and De Jong (1991b, 1993)
Provided learners with a hypothesis scratchpad where learners were offered different windows for selecting variables, relations and conditions allowing learners to assemble hypotheses themselves.
Kim, Evens, Michael, & Rovick, (1989)
Provided their students with a predefined spreadsheet for providing their ideas. These spreadsheets asked the students to predict qualitatively what would happen with the components of the system in question.
Haque, Rovick, & Evens, (1989)
Njoo and De Jong (1993a, 1993b)
Went one step further and provided the students with a list of predefined hypotheses. They concluded that offering predefined hypothesis positively influenced the learning process and performance of learners.
Quinn and Alessi (1994)
Forced students to write down an hypothesis or list of hypotheses before conducting the experiment. The intention was that students would be able to eliminate hypothesis. This strategy lead to positive results only when the complexity of the simulation was low. For the case of a higher level of complexity, no advantage was found.</td></tr>
<tr><td>Njoo and De Jong (1993)
Found that 42% on average of the students showed a syntactical correctness of the learning process, and lower scores for the specific process of generating hypothesis</td></tr>
<tr><td>Klahr and Dunbar (1988)
Found that students may retain hypotheses incorrectly on the basis of a negative experimental result. They described how students may not be able to state or adapt hypotheses on the basis of data gathered. 56% of students failed to draw the right conclusions from disconfirming experiments.
The authors also found a "reverse effect in which learners rejected hypotheses in the absence of disconfirming experimental outcomes (p. 183).</td></tr>
<tr><td>Dunbar (1993)
Found evidence in his studies of having an overall difficulty with dropping an original goal. He discussed that this leads them to persist in holding an initial hypothesis rather than stating a new one. He calls this problem the "unable-to-think-of- an-alternative-hypothesis (p. 183)"</td></tr>
<tr><td>Van joolingen and de Jong (1993)
Klayman and Ha (1987)
Klahr, Fay, and Dunbar (1993)
Identified that learners may be led by wrong or inconsistent considerations. For example, considerations that do not necessarily help them to find the correct theoretical principles. Also, they found that students tend to avoid hypotheses that have a high chance of being rejected.</td></tr>
<tr><td>Kuhn, Schauble, and Garcia-Mila (1992)
They found that 10 year old students changed their ideas on the causality of a domain variable many times during an experimentation session. The main factor influencing this behavior may be due to the fact that subjects employed a large repertoire of "invalid inferences."</td><td>Van joolingen & de Jong, 1997
Identified the distance between the theoretical variables that are manipulated in the simulation as a possible aspect that may influence student's ability to adapt hypotheses on the basis of data.</td><td>Glasser et al. (1992)
Suggested that in environments where a relatively small distance exists between the theoretical variables and the variables that can be manipulated in the simulation, is easier for learners to identify the relation between a) their manipulations of such variables and b) the characteristics of the theoretical models.</td></tr>
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a1 Maybe the information should be given during the interaction with the simulation tool.
admagana, 7/16/2008

Problems related to Designs of Experiments

Problem	Possible cause of the problem	Possible solution to the problem
Wason (1960) Klayman and Ha, 1998 Identified that students had a tendency to seek information that confirms a hypothesis instead of trying to disconfirm the hypothesis. Authors also pointed out that seeking confirming evidence is not the best strategy to follow.	Dunbar (1993) Showed in a simulation environment that some students have a strong inclination to search for evidence that supports their current hypothesis, and that this inclination may prevent them from stating an alternative hypothesis, even when they are confronted with inconsistent evidence.	Klahr, Dunbar, and Fay (1991, p. 391) Identified that a number of heuristics for experimentation in their simulation environment may be successful. Among their heuristics are: Design simple experiments to enable easy monitoring Design experiments that give characteristic results Focus on the dimension of a hypothesis Exploit surprising results Use the a priori strength of a hypothesis to choose an experimental strategy Rivers and Vockell (1987) Provided the learners with hints such as “It is wise to vary only one variable at a time (p.188)” This strategy had effects on the students’ experimentation abilities but no effect on the learning otucome. Shute & Glaser, (1990) Presented students with hints that were generated dynamically based on the actual experimentation behavior of the learners. Leutner (1993) Provided the students with adaptive advice based on students’ experimentation behavior. He found that if the advice had a limited level of detail, it helped the learner to increase his/her domain knowledge but inhibited the acquisition of functional knowledge. However, if the advice was very detailed it also helped students acquire functional knowledge.
Quinn and Alessi (1994) Found that in a small number of cases (one of six in a sample of 179 subjects) did students conduct experiments with the intention of eliminating hypotheses. In this study, students were asked to choose the purpose of the experiment from a series of alternatives presented before actually running the experiment.		
Wason (1966) Identified the phenomenon of “inconclusive experiments (p.184).” This phenomenon refers to when subjects do not always behave as logical thinkers and do not perform the actions that would be most effective for testing a hypothesis.		
Glaser et at. (1992) Identified that learners tend to vary too many variables per one experiment resulting in not being able to draw any conclusions.		
Reimann (1991) Observed in the domain of optics that students designed poor experiments that do not allow them to draw univocal conclusions.		
Van Joolingen and De Jong (1991b, 1993) Found that learners often manipulated variables that had nothing to do with the hypothesis they were testing.		
Shute and Glaser (1990) Glaser et al. (1991) Reported that unsuccessful learners do not gather sufficient data before drawing conclusions.		
Kuhn et al. (1992) Found that their participants did not use the whole range of potential informative experiments that were available, but only a limited set. Some of the participants designed the same experiment several times. This phenomenon is called “inefficient experimentation behavior (p. 185)”		
Schauble, Klopfer, and Raghavan (1991) Identified that students adopt an engineering approach attempting to create some desirable outcome instead of trying to understand the model. An engineering approach leads to a much narrower search than a scientific approach and to a concentration on those variables where success is expected. As a consequence, this approach may prevent learners from designing experiments that provide well organized data that are sufficient for discovering all relevant domain relations. Schuable Glasser, Duschl, Schulze, and John (1995) Njoo and de Jong (1993a)		
White (1993) He reported that in his study involving games in a simulation environment, students created experiments that were fun instead of experiments that provided insight into the model.		

Problems related to Interpretation of data

Problem	Possible cause of the problem	Possible solution to the problem
Klahr et al. (1993) Found that subjects misencoded experimental data. Linn, Layman, and Nachmias (1987) Found that students' graphing abilities increased as a result of working with the simulation in question, but that on the more complicated graphing skills (for example, comparing different graphs) difficulties still existed after the course in question.	Klahr et al. (1993) Suggested that the hypothesis that the learners hold may direct the interpretation of data. This may lead to misinterpretations of data most likely resulting in a confirmation of a current (perhaps wrong) hypothesis Chinn and Brewer (1993) Kuhn et al. (1992)	Schauble, Glaser, et al. (1991) Successful learners are more proficient in finding regularities in the data than unsuccessful learners Lewis et al. (1993) Provided to the students with a graphic tool that allowed them to draw a curve to depict their predictions. Feedback was provided to the learners by showing them the correct curve in the same diagram in which the initial student's prediction was drawn. Tait (1994) Provided to the students with a graphic toll allowing them to draw a curve depicting their predictions. In this case, feedback also included explanations of the differences between the system's curve and the learner's curve. Reimann (1991) Provided an environment that allowed students to make predictions at three different levels: as numerical data, as a drawn graph and as an area in which the graph would be located.

Problems related to regulation of discovery learning

Problem	Possible cause of the problem	Possible solution to the problem
Charney, Reder, and Kusbit (1990) Reported goal setting as a problems for subjects with low prior knowledge	Lavoie and Good 1988 Simmons and Lunetta 1993 It is frequently reported that successful learners use systematic planning and monitoring, whereas unsuccessful learners work in an unsystematic/ random way. Veenman and Elshout (1995) Found that individuals with a high intellectual ability showed a better working method than individuals with low intellectual ability	Shute and Glaser (1990) Glaser et al. (1992) Schuable, Glaser, et al. (1991) Claimed that successful learners plan their experiments and manipulations to a greater extent and pay more attention to issues of data management Glaser et al. (1992) Mentioned persistence in following a goal as a characteristic of good learners, these successful subjects were also ready to leave a route when it apparently would not lead to success. Lavoie and Good 1988 Schauble, Glaser et al. (1991) Fund that good learners make more notes during learners and recorded data more systematically. De Jong & Njoo (1992) Identified that two aspects that can support regulative learning processes are model progression and the structuring of the discovery process. White and Frederiksen (1989,1990) Introduce to learners Quest, an application that introduced different aspects step by step. Quest introduced to students electrical systems and models of electrical circuits differing in order such as qualitative or quantitative models; differing in degree of elaboration considering the number of variables and relations between variables; and differing on perspective, such as functional to a physical one. This sequence of instruction assumes the transition from novice to expert approach. Swaak, Van Joolingen, and De Jong (1998) Evaluated the progression of model in the level of complexity. They used SETCOM, a harmonic oscillation simulation where the model progresses from free oscillation to damped oscillation to oscillation with an external force. The authors found that this model progression had an effect in students' intuitive knowledge, but no effect on students' definitional knowledge. Quinn and Alessi (1994) However, in later studies it has also been found that model progression has not had an effect. Quinn and Alessi conducted an study in which different groups manipulated different variables ranging from two to four. The group with access to two variables then proceeded to have access to three and then to four. For this particular case the variables did not interact and the model was quite simple. Alessi (1995) Conducted a study using a more complex simulation. He found that increasing the level of complexity gradually, was beneficial for initial learning and transfer. Reieber and Parmley (1995) Found that students when provided an increasing control over variables scored higher than students who could exercise control on its full complexity from the beginning.

Problems related to regulation of discovery learning (contd.)		
Problem	Possible cause of the problem	Possible solution to the problem
		Charney et al. (1990) Suggested that planning support may un-overload students working capacity helping them to manage their learning process. Showalter (1970) Zietsman and Hewson (1986) Tabak, Smith, Sandoval, and Reiser (1996) Recommended using questions as a way to guide the learner through the discovery process. This eventually helped learners to focus their attention to specific aspects of the simulation. White (1984) Introduced a technique of setting goals in a simulation of Newtonian mechanics. De Jong et al. (1994) Suggested different types of assignments that can be used with a simulation tool: Investigation assignments which included prompts to find the relation between two or more variables Specification assignments intended to request form students to predict a value of a certain value And explicitation assignments that asked the student to explain a certain phenomenon in the simulation environments. Swaak et al. (1988) De jong, Hartel, Swaak, and van Joolingen (1996) Offered students optional assignments such as the ones described above. They found that students used these assignments very frequently and these had positive effect on learners intuitive knowledge. Reimann (1991) Shute & Glasser (1990) Glaser et al. (1988) Lesgold, Lajoie, Buzo, & Eggan, (1992) Schauble, Raghavan, and Glaser (1993) Provided learners with the ability to store numerical and nominal data from experiments. This data in the notebook could be manipulated so students can sort values, select experiments in which a specific variable had a specified value, and calculate equations. Where in some cases students can receive upon request an overview of all the actions they have taken so far. Further more in the case of the one used by Schauble et al., students were able to group actions under goal and to ask for an "expert view" that gave the relevance for the student's actions in the context of a specific goal. Reimann and Beller (1993) Propose a system that selects previous experiments in the basis of similarity in order to provide the learner a comparison point. Linn and Songer (1991) Found positive effects in providing students with a sequence of experimentation steps and detailed directions in each of the steps. Njoo and De Jong (1993b) Provided a structuring process requesting from students to write down: the variables and parameters, hypotheses, experiment, prediction, data interpretation, and conclusion. These students performed better in qualitative insight than students who worked with the simulation tool alone. Gruber, Graf, Mandl, Renkl and Stark (1995) Found that students (60) who receive instruction in making predictions, comparing predictions to outcomes, and drawing inferences outperformed a second group of students (60) that did not receive any guidance. White (1993) Forced her students to follow a systematic process consisting of four phases: a) asking questions, b) doing experiments, c) formulating laws, and d) investigating generalizations. At the same time, she provided scaffoldings in each phase. She found an effect of this approach on a test measuring qualitative predictions of real-world situations compared to students exposed to traditional curriculum. Veenman and Elshout (1995) Veenman, Eshout, and Busato (1994) Exposed students to a structured environment consisting of task assignments were prompted to paraphrase questions, generate hypothesis and prepare a plan of action. They found no overall effect between the structured environment and a group of students exposed to an unstructured environment. They found that students who benefited the most from these approach were the low-intelligence ones. Lewis et al. (1993) Shute and Glaser (1990) Compared groups of students exposed to structured simulation environments versus traditional expository instruction. For the case of Lewis, he requested students to keep a sort of journal in which learners had to write down notes about graph comparisons, conclusions after each experiments, everyday examples and important notes, and notes about confusion points. They found positive results of students exposed to the structured simulation environment. For the case of Shute and Glaser, students were guided through a fixed set of sequential actions. Authors concluded that in a test focused on recalling of concepts, students exposed to the structured simulation environment failed to show an advantage over the traditional lesson. But the authors pointed out that the learning was more effective.

Purpose of the study	Hypothesis	Participants	Instruments and Data Analysis	Design and Procedures	Findings
The purpose of this study is to describe the use of computer simulations for learning. The authors first give a short introduction to the terms computer simulations and scientific discovery learning followed by a short overview of studies that compared unsupported simulation-based discovery learning to some form of expository teaching.	What are the problems that learners have in discovery learning, and how can we design simulation environments that support learners in overcoming these problems?				