

Regulative support during inquiry learning with simulations and modeling

Sarah Manlove

▶ **To cite this version:**

Sarah Manlove. Regulative support during inquiry learning with simulations and modeling. 2007. hal-00190075

HAL Id: hal-00190075

https://telearn.hal.science/hal-00190075

Submitted on 23 Nov 2007

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Regulative support during inquiry learning with simulations and modeling

Doctoral Committee

Chair:	Prof. dr. E.R. Seydel
Promotor:	Prof. dr. A.J.M. de Jong
Assistant Promotor:	Dr. A.W. Lazonder
Members:	Prof. dr. R. de Hoog
	Dr. W.R. van Joolingen
	Prof. dr. J.M. Pieters
	Prof. dr. B.H.A.M. van Hout-Wolters
	Prof. dr. P.A. Kirschner
	Prof. dr. M.L.L. Volman

The research reported in this dissertation was funded by the Co-Lab project through a grant made possible by the European commission under project number IST-2000-25035.

Copyright 2007 Sarah Manlove
Print Partners Ipskamp, Enschede

All rights reserved. No parts of this publication may be reproduced, in any form or by any means, without written permission from the author.

REGULATIVE SUPPORT DURING INQUIRY LEARNING WITH SIMULATIONS AND MODELING

DISSERTATION

to obtain the degree of doctor at the University of Twente on the authority of the rector magnificus, prof. dr. W.H.M. Zijm on account of the decision of the graduation committee, to be publicly defended on Thursday October 25th, 2007 at 16:45

by

Sarah Manlove
born on January 12th, 1969
in Schenectady, New York, U.S.A.

Dit proefschrift is goedgekeurd door de promotor:
Prof. dr. A.J.M. de Jong

En assistant-promotor:
Dr. A.W Lazonder

This book is dedicated to my parents, Linda and Jim, and my brother Jim and his wife Tracy.

Acknowledgements

When we take a moment and examine ourselves and our thoughts we come up with answers, often unexpected ones, which further our own knowledge construction processes and self-knowledge. Naturally throughout the research and writing of this dissertation on self-regulation, I turned a critical eye to my own regulative skills. These "thought investigations" sometimes found improvement, and often steps backward, but always a wish to improve or maintain as warranted. In many cases people were attached to those thoughts; people so numerous and important that I beg patience with the length of my acknowledgements. People who made this dissertation possible and better and who, *e re nata*[1], made my own self knowledge possible and better.

Ard Lazonder is such a person. I could speak volumes about what I have learned from this man. His coaching taught me elegance and efficiency, and that something can always result from research. This dissertation naturally would not be what it is without his guidance, thoughts, and input. Ton de Jong is another from whom I've learned more than can be written here. Perhaps most importantly, he taught me to truly see critically, without making value judgments, and to understand the nobility of the scientific method. Wouter van Joolingen reminded me of the beauty and wonder of physics, and how we model our understanding. Hans van der Meij helped me see the value of my own views and feelings at very critical times during my research, a fact for which I am eternally grateful. The support of Larisa Leerkamp taught me grace even in trying circumstances.

Susanne Ootes, Amber Walraven, and Sylvia van Borkulo, offered graceful assistance and taught me humor when collecting and analyzing data. Without their help these studies wouldn't have been possible. My fellow PhD students and instructional technology dept members taught me much about expectations, adaptation, and the importance of having perspective. I appreciate this more than I can express or explain. Jakob Sikken, in particular taught me to be clear in communicating technical needs, and put in tireless hours implementing them.

This dissertation wouldn't have been possible without the people of the Co-Lab consortium, and Re-Coil projects, two ambitious undertakings which funded this research. Both staffed with people full of passionate

[1] E re nata- latin for "as circumstances dictate"

hard work for what they were doing, and whom are unfortunately too numerous to mention by name here.

Naturally this research would not have taken place without the help and assistance of the schools, students, and teachers who participated. Once again, I can't mention you all by name, but I'd like to extend a special thanks to; Peter Wester, Frans Carelsen, Christine Mak, Marcel Iedler, Jonathan Briffa, Dave Gould, Moussa Adam, Maire Ni Shlatara, Amit Chatterjee, Zeger-Jan Kock, Andrew McGregor, Wim Reimert, Andrew Ricker, and Kevin Hulbert for their support, enthusiasm, and interest.

My gratitude can't be expressed enough to Jan-Maarten Luursema for his excellent work on the graphics and the cover art for this dissertation.

Finally, I'd like to acknowledge the moral support of; Linda Mahnken, Jan-Maarten Luursema, Bas Kolloffel, Bregje de Vries, Jan van der Meij, Hannie Gijlers, Francis Leusink, Susan, Kevin, & Skyler McKenney, and Harini Ravel; and of my parents, James and Linda, and my brother, Jim, and his wife Tracy. Through listening to me, sharing your thoughts, and lending moral support you all afforded this dissertation. Thank you for putting up with me throughout the trials of this process.

I humbly thank and acknowledge all of these good people for the opportunities to learn, and for their guidance, patience, and time. I have only benefited from your help and insights, and it is from you all….ancora imparo, I am still learning, and always will.

Table of Contents

List of Figures v

List of Tables v

A note on the quotations... vi

1. Situating inquiry learning and regulation 1

1. Introduction 2

2. Inquiry learning 3
2.1. Inquiry learning processes 4
2.2. The role of domain models 6

3. Regulative processes 7
3.1. Planning 8
3.2. Monitoring 9
3.3. Evaluation 10
3.4. Collaborative regulation 10

4. Student difficulties with inquiry learning 11
4.1. Orientation problems 11
4.2. Hypotheses generation problems 12
4.3. Experimentation problems 13
4.4. Conclusion problems 14
4.5. Modeling problems 14
4.6. Regulative problems 15

5. Problem statement 16

6. Dissertation overview 17

2. Situating the research: Co-Lab and its tools 19

1. Origins and development 20

2. A metaphor 20

3. Co-Lab's interface 22

4. The cognitive tools, by room 23
4.1. The hall 23
4.2. The lab 23
4.3. The theory room 24
4.4. The meeting room 27

5. The Process Coordinator (PC) 28

6. Conclusion 28

3. Exploring task approach, collaboration, and regulative patterns **31**

1. Introduction 32

2. Method 34
2.1. Participants 34
2.2. Materials 34

3. Procedure 35

4. Measures 36
4.1. Log files 36
4.2. Working patterns and regulative activity 37
4.3. Regulative communication 37

5. Results 38
5.1. Navigation 38
5.2. Collaboration 40
5.3. Approach to the learning task 41
5.4 Regulative tool use 44
5.5. Regulative communication 45

6. Discussion 50

4. Examining regulative scaffolds during inquiry learning **53**

1. Introduction 54

2. Self-regulation framework 56

3. Method 58
3.1. Participants 58
3.2. Materials 58
3.3. Procedure 59
3.4. Coding and scoring 60
3.5. Data analysis 62

4. Results 62
4.1. Learning outcomes 62
4.2. Learning activities 63
4.3. Correlations 64
4.4. Qualitative analyses of verbal interaction 65

5. Discussion 67

5. Refining regulative scaffolds during inquiry learning **71**

1. Introduction 72

2. Self-regulation in inquiry learning 73
2.1. Planning 73
2.2. Monitoring 73
2.3. Evaluation 74

3. Problems and solutions 75

4. Investigating regulative tool support 76

5. Method 77
5.1. Participants 77
5.2. Materials 77
5.3. Procedure 79

6. Coding and scoring 79
6.1. Learning outcomes 79
6.2. Regulative activities 80
6.3. Data analysis 81

7. Results 81

8. Discussion 84

6. Collaborative versus individual use of regulative scaffolds 89

1. Introduction 90

2. Method 93
2.1. Participants 93
2.2. Materials 93
2. 3. Procedure 95

3. Coding and scoring 95
3.1. Learning outcomes 95
3.2. Regulative tool use 96
3.3. Data analysis 96

4. Results 97

5. Discussion 99

7. Synthesizing the research 103

1. Introduction 104

2. Regulative activities 104
2.1. Planning 104
2.2. Monitoring 107
2.3. Evaluation 109

3. Learning outcomes 110

4. Learning conditions 112

5. The future of regulative support 114

English summary 117

Introduction 117

Study 1: Exploring task approach, collaboration, and regulative patterns 118

Study 2: Examining regulative scaffolds during inquiry learning 119

Study 3: Refining regulative scaffolds during inquiry learning 120

Study 4: Collaborative versus individual use of regulative scaffolds 121

Conclusion 122

Nederlandse samenvatting **125**

Inleiding 125

Studie 1: Een verkennend onderzoek naar de werkwijze, samenwerking en regulatie tijdens onderzoekend leren 126

Studie 2:Regulatieve ondersteuning bij onderzoekend leren 127

Studie 3: Het verbeteren van regulatieve ondersteuning bij onderzoekend leren 128

Studie 4: Collaboratief versus individueel gebruik van regulatieve ondersteuning 130

Conclusie 130

References **133**

List of Figures

Figure 1-1. Inquiry Learning Processes 4
Figure 1-2. Example Simulation (left) and domain model (right) 7
Figure 2-1. Co-Lab Login Screen 21
Figure 2-2. Hall in Co-Lab 23
Figure 2-3. Lab work space and tools 24
Figure 2-4. Theory room work space and tools 25
Figure 2-5. Qualitative and Quantitative Model Specification 26
Figure 2-6. Meeting room workspace with tools 27
Figure 2-7. PC with tabbed views (1) 28
Figure 3-1. Water tank simulation 36
Figure 3-2. Room change patterns 40
Figure 3-3. Room patterns by group 42
Figure 4-1. PC with tabbed views (2) 59
Figure 4-2. Reference model for the experimental task. 60
Figure 5-1. Goal tree view (left) and History view (right) of the PC+ 79
Figure 5-2. Model quality scores by condition and achievement level 84
Figure 6-1. PC tabbed views (3) 94

List of Tables

Table 2-1. Co-Lab interface tools 29
Table 2-2. Room-specific tools 29
Table 3-1. Overview of operational tools and their location 34
Table 3-2. Sample log file 36
Table 3-3. Number of room visits and length of stay per group 38
Table 3-4. Use of the Process Coordinator tool (PC) 44
Table 3-5. Table 3 Classification of utterances 45
Table 3-6. Occurrence rates of regulative episodes 46
Table 4-1. Mean scores learning outcomes and learning activities 63
Table 4-2. Correlations: model quality and learning activities by condition 64
Table 5-1. Summary of overall learning activities and outcomes 82
Table 5-2. Frequencies of tool use for regulative activities 83
Table 5-3. Correlations: regulative tool use and learning outcomes 85
Table 6-1. Summary of overall learning activities and outcomes 97
Table 6-2. Frequencies of tool use for regulative activities 98

A note on the quotations…

Each chapter of this dissertation begins with a quote. All of the quotes come from the same source; a fiction book called *The Diamond Age, or A Young Lady's Illustrated Primer* by Neil Stephenson. I have often returned to this book for inspiration about technology-enhanced learning environments and their design. For this reason I wanted to give the book a voice within my dissertation by using select quotations to give the reader a sense of each chapter. However, unfamiliarity with the book may make it difficult for the reader to understand these quotes. A synopsis of the relevant contexts from the book to the quotations is given below to address this issue.

The Diamond Age, on one level, is about an electronic book or, "the primer" as it's called. The primer is, in fact, more than a book. It is a technology-enhanced learning environment. Developed and programmed by a character called "Hackworth" the primer accidentally falls into the hands of a little 4 year old girl, Nell. She uses it until the conclusion of Stephenson's novel when she is around 19. The primer operates in such a way as to "read" a child's environment and then "map" the child's psychological terrain onto a schema-based representation of folk tales for the purposes of learning. Among many other things the primer teaches Nell to read, to defend herself, and how to reason. It can be thought of as an immersive virtual world where Nell interacts with simulations and simulated characters to solve increasingly complex problems as her alter ego "Princess Nell".

Unbeknownst to Nell initially, there is another person behind the scenes. Miranda is an actress or "ractor" as they are called. Ractors are implanted with nano-technology that allows their appearance to change into virtual characters in the interactive entertainment business known as "ractives" (immersive virtual reality shows where the audience participates and acts with the ractor). She works from an individual booth in a theater called "The Parnass", and takes jobs from a teleprompter that tells her what to say. Miranda becomes increasingly interested in "the primer job" and establishes a relationship with Nell despite the fact that neither knows who the other is. Towards the end of the novel Nell goes in search of Miranda because she recognizes her influence behind the Primer. Miranda's theater boss assists Nell in her efforts.

1. Situating inquiry learning and regulation

Abstract

This chapter situates inquiry learning and regulatory skill together in order to contextualize the research question driving the studies of this dissertation. The principles and processes of inquiry learning are presented followed by a model of self-regulation. Problems students have with both inquiry learning and its regulation are then discussed. This chapter concludes with a problem statement and overview of the chapters of this dissertation.

"And thenceforth it will see all events and persons in relation to that girl, using her as a datum from which to chart a psychological terrain, as it were. Maintenance of that terrain is one of the book's primary processes. Whenever the child uses the book, then it will perform a sort of dynamic mapping from the database onto her particular terrain" (Stephenson, 1995, p. 94).

1. Introduction

This dissertation is about providing support to secondary students during technology-enhanced inquiry learning. With reference to this learning setting Quintana, et al, (2004) state "These learning contexts consist of more authentic, challenging, and open-ended problems and thus require significant disciplinary knowledge and metacognitive skills" (p. 338). Collectively the four studies described investigate how support can be designed to help students with the latter: metacognitive skills with a special emphasis on regulatory aspects. Aspects that assist students with charting and maintenance of their psychological terrain, as it were, helping them plan, monitor and evaluate what they did and learned. Specifically, the studies described in this dissertation investigate the instructional effectiveness of scaffolds to promote these processes.

Teachers often take responsibility for such *regulative* functions to support their students. Any time a teacher asks questions like "What are you supposed to be doing now?" or "What do you think it means?" or "Does that make sense?" their aim is to assist students with aspects such as attention focus, goal setting, or explaining and checking comprehension. All of these aims are meant to help students manage environmental contingencies, and give them a sense of personal agency to act on goal attainment for learning (Zimmerman, 2000). However, the advent of technology-enhanced environments and learning modes which stress student-centered approaches often demand increased *student* responsibility for their own psychological terrain during learning (De Jong *et al.,* 2005). Researchers and educators worry however, that students often have difficulty minding their own thinking during educational experiences. Particularly within technology-enhanced settings, where as (Land, 2000) states, "Rapid advances in computer technologies have facilitated the development of electronic tools and resources that have in turn, expanded the opportunities to empower student-centered learning alternatives. Although at face value the potential of these opportunities is compelling, the extent to which learners 'mindfully' engage them is not at all certain" (p. 61).

In order to fully grasp how students can be supported in being mindfully engaged and what that looks like, it is necessary to do so within the context of the learning that is taking place. Towards this end, this chapter seeks five aims: 1) to provide a description of inquiry learning; 2) touch on

technology-enhanced aspects important to this dissertation's context; 3) describe regulative skills within this learning mode and dissertation; 4) discuss difficulties students have with both inquiry learning and regulation; 5) provide a general problem statement which forms a theoretical base and overarching research question within this dissertation. In conclusion this chapter gives an overview of the research studies which sought to address these issues.

2. Inquiry learning

The National Research Council published its report on How People Learn in 2000. This report called for methods of science instruction that enable students to construct scientific understanding through an iterative process of theory building, criticism, and refinement based on their own questions, hypotheses, and data analysis activities. They further expound that question posing, theorizing, and argumentation should form the structure of students' scientific activity (Bransford, Brown, & Cocking, 2000).

These methods of science instruction encapsulate inquiry learning and were proposed by John Dewey as early as 1938 (Dewey, 1938) and later in the work of Jerome Bruner (Bruner, 1961). Inquiry learning's development in education was enhanced more recently by cognitive constructivist views of education which hold that students build or create understanding by experience (Duffy & Jonassen, 1992). In other words, "The experience in which an idea is embedded is critical to the individual's understanding of and ability to use that idea" (p. 4.). When students conduct activities such as described by Bransford et al., (2000), they replicate the *experience* of science. This in turn, it is argued, promotes better learning of both science domain concepts, but also of the processes of scientific reasoning (Edelson, Gordin, & Pea, 1999). Specifically its activities help students integrate past and present knowledge (Linn, 1995) and focus on student-driven inference building (De Jong et al., 1998) among other important higher-order thinking skills (c.f. Kuhn *et al.,* 2000). To illustrate, past knowledge of a science topic could be held in a student's hypothesis, which is then tested through experimentation, and leads him or her to link it to new knowledge located within inferences about the topic generated from data results. This process promotes understanding that in turn aids memory and transfer of knowledge to new situations (Lieberman, 2004; Mayer, 2002).

2.1. Inquiry learning processes

To answer this call for authentic science activities to be situated within science work, several researchers have identified a series of processes that are used in conducting a scientific inquiry (c.f. De Jong & Van Joolingen, 1998) These process frameworks follow the scientific method which mimics the steps scientists use to discover new knowledge (De Jong, 2006a). Njoo and De Jong (1993) divided the scientific method processes into two broad categories (see Figure 1-1): *transformative* and *regulative*. Transformative processes are those in which students directly create domain knowledge i.e., they generate new information and knowledge. They are orientation: hypothesis generation; experimentation; and conclusion Executive control of the learning process is considered in their model to be regulative in nature. These include planning, monitoring, and evaluation. (Evaluation can also yield new information, and is considered to fall under both transformative and regulative categories). The following paragraphs describe transformative processes from the view of an "ideal" student, conducting an inquiry learning task. Regulative processes will be further described in section 3 of this chapter.

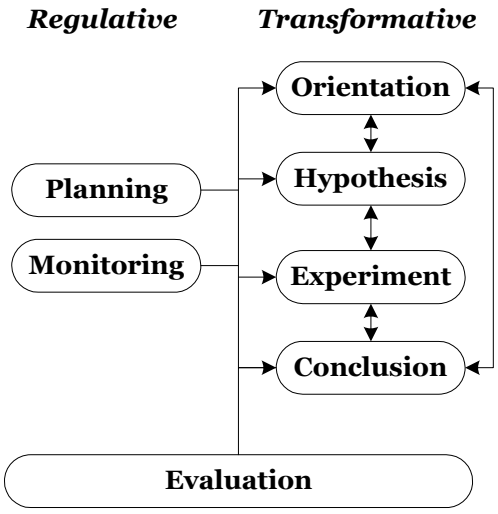


Figure 1-1. Inquiry Learning Processes

Orientation begins when students explore the domain and determine, or refine what their academic task is. During orientation students might identify or formulate a question, or get a sense of the science domain or topic. Students seek relevant information during this phase, such as variables or relationships important to the topic of the investigation.

Hypothesis generation is the process of defining alleged relations between one or more variables and parameters in the science topic under investigation. The most common form a hypothesis takes is a propositional, "If-then" statement (e.g., if the water level in tank increases, then the outflow rate increases). Ideas about a domain can also be stated less formally and take the form of a problem statement called issues by De Jong (2006b) that guide student inquiry activities. A hypothesis or issue is stated with the intention of testing it as being true or false, or in need of change in the following phase.

Experimentation includes set-up and design of resources to test specific hypotheses or the issues generated in the previous two phases. Students change values of variables to see if they can prove or disprove a hypothesis or more precisely quantify the variables or relationships under investigation, such as with an issue. Students also analyze and interpret output data generated from the experiments they conduct.

Conclusions are formed when students take the results generated through their experiments and make inferences about their domain ideas, hypotheses, or issues. Specifically scientific inquiry states that students are to decide the state of their hypothesis in the conclusion phase.

Inquiry learning is considered cyclical and iterative (as indicated by the arrows in Figure 1-1), rather than linear. Scientific inquiry is not always conducted in a straightforward manner, neither is the thinking of an actual scientist. To illustrate data from an experiment might send one back to the beginning to orient a bit more before conclusions can be drawn, or a conclusion can result in a new hypothesis. As such it is not expected that students will follow the transformative processes linearly during their investigations.

2.2. The role of domain models

Within this dissertation high school students conducted inquiry processes within a technology-enhanced learning environment. This environment is described in detail in chapter 2. While the activities described above are not always conducted with technology, technical advances have enabled unique opportunities to allow students to actively work with a domain and build understanding. One important feature of technology-enhanced learning environments which incorporate simulations is that they are based on what is known as the *domain model*.

Domain models constrain or create boundaries of a topic the student works with. The model describes not only the variables but also their relationships. Within technology-enhanced learning environments domain representations, such as a simulation of scientific phenomena, will disclose variables, from which students determine relationships during the inquiry task (Hulshof, 2001). Inquiry learning environments do this in a variety of ways, although one primary way is through a computer simulation which "…contains a model of a system (natural or artificial) or a process" (De Jong & Van Joolingen, 1998, p. 180). The simulation is thus used as the vehicle through which students conduct their inquiry, and "discover" the investigated domain or its principles.

An example of the simulation students used in the studies of this dissertation with part of its domain model is found in Figure 1-2. This simulation can be used to investigate water flow in and out of a tank. Scientific principles such as Bernoulli's equation, or Torricelli's law can be discovered by students as they can vary tank specifications, and water inflow and level. The model, shown right is a depiction of the underlying rules which govern the behavior of the simulation. It shows how water volume and outflow rate are dependent upon aspects such as the level of the water currently in the tank, the speed at which the water flows out, and the structure of the tank and its drain.

Often students are asked to create their own models as a means of expressing knowledge gained during scientific inquiry. Recently best-practices for science teaching with inquiry learning have called for model building to be incorporated as a skill within science (Penner, 2001; Stewart *et al.,* 1992). White and Frederiksen (1998) incorporated scientific model building into their theoretical perspectives on the design of the Thinkertools curriculum. Stating that "complex theories in science are developed through a process of successive elaboration and refinement in which scientific models are created and modified to account for new

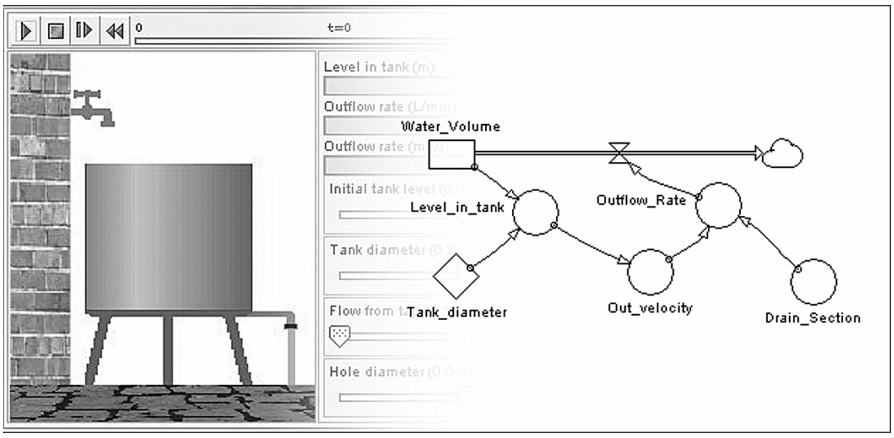


Figure 1-2. Example Simulation (left) and domain model (right)

phenomena" (p. 7). Thus the building and refining of domain models helps make student understanding of a domain explicit.

Student modeling can take the form of mathematical equations, or by more qualitative means such as making a concept map. System dynamics modeling, as shown in Figure 1-2, make it possible for students to create "concept-map-like" drawing with generic variable types (such as stocks, auxiliaries, constants, and flows), and then specify them. These types of models can then be run to produce data which can be used to refine their models, or be compared to a simulation or other phenomena's data. Further information about system dynamics modeling is covered in chapter 2, section 4.3. Inquiry learning environments which incorporate both simulations and the capacity for student-constructed models give students the tools they need to scientifically reason and express their understanding in representations appropriate to science.

3. Regulative processes

In order for students to reap the benefits of understanding a domain model, other important processes must occur. Students must regulate their learning. Regulation is considered to be an aspect of metacognition, a term coined by Flavell, (1971) to indicate the "…notion of thinking about one's own thoughts" (Hacker, 1998, p.3). The process of thinking about one's own thoughts affords two components: knowledge of cognition, and regulation of cognition (Brown, 1987; Jacobs & Paris, 1987; Schraw & Moshman, 1995)

A student's knowledge of cognition includes awareness of his/her thinking, background knowledge, and strategies for learning (Gredler,

1997). Throughout learning students have the opportunity to gain an understanding of concepts and facts, how to perform a task (strategies), and when, why, and where to apply this knowledge. Regulation of cognition differs from knowledge of cognition in that it is the active engagement and application of a student's knowledge of cognition (Jacobs & Paris, 1987). Veenman, Prins, and Elshout, (2002) refer to this active engagement as the application of metacognitive skills which "…concern the self-regulatory activities actually being performed by a learner in order to structure the problem solving process" (p. 328). Three activities are generally thought to be essential for self-regulation: planning, monitoring, and evaluation (Butler & Winne, 1995; Schraw, 1998; Zimmerman, 2000). As these phases resemble the regulative activities students should engage in during inquiry learning (Njoo & De Jong, 1993) valuable insights for the design of regulative support during inquiry learning might be gleaned from models of self-regulation.

While many self-regulation models include a behavioral and motivational aspect (cf., Kuhl, 2000) the research presented in this dissertation focuses on what Pintrich (2000) calls *cognitive* regulation. That is, how students engage in a recursive process which utilizes feedback mechanisms to direct and adjust their learning and problem solving activities (Azevedo, Guthrie, & Seibert, 2004). This dissertation uses the terms, self-regulation and regulation interchangeably.

The next section describes the general processes of regulation which formed the theoretical base for the research in this dissertation. It should be noted that different aspects of the model of cognitive regulation evolved and were emphasized in the research studies. This was due to the formative nature of the context in which the technology-enhanced learning environment was developed. As such the model described in this chapter depicts the basic elements formed from *all* the studies; specific self-regulation model features relevant to the study under investigation are left for depiction within the empirical chapters.

3.1. Planning

In the planning phase of inquiry learning students utilize transformative orientation activities to set goals, and make a strategic plan. Specifically students begin to familiarize themselves with both the task and the resources available. This information serves as input to setting an overall learning outcome, or learning product goal, and also for setting sub-goals for how to achieve them. For example, students faced with the water tank simulation shown in Figure 1-2 might explore the variables and run the simulation a few times. These orientation activities assist students to define for themselves what variables are important for hypotheses formation or experimental designs. Insights derived from these initial runs are used to make plans for how to approach the inquiry task.

Highly self-regulated learners organize their goals hierarchically, such that process goals operate as proximal regulators of more distal outcome goals (Zimmerman, 2000). These steps convey the students' ideas for how to approach super ordinate goals through subordinate sub-goals, creating cognitive strategies for task fulfillment. In the tank lab simulation example shown in figure 1-2 for instance, students might determine the top goal of making a model, but break that goal down into; exploring the simulation for important factors, determining all important variables in their model, and specifying variables and relationships. Collectively, the sub-steps to making a model then become the strategy students use to tackle their task. Butler and Winne (1995) argue that implicit standards are developed from task characteristics and goals as well. While reading an assignment about the water tank, for example, students develop the understanding that one criterion for their model is that it must be constructed in such a way as to be "runnable" that is, produce data. These criteria are invaluable to students while they move through task execution to monitor their understanding and progress.

3.2. Monitoring

Throughout the execution of their plans, students ideally monitor what they are doing to ensure that they are making progress toward their specified goals (Ertmer & Newby, 1996). Monitoring can occur at any moment during task execution, depending in part on the students' actions and the results thereof (Brown, 1987). As such it is an oversight function which is activated to determine task progress, if goals or task criteria are being met and to check comprehension (Butler & Winne, 1995; Gredler, 1997; Zimmerman, 2000). Monitoring involves actions such as tracking attention, reviewing the status of a learning product, or goal, and checking comprehension.

Ideally the results of monitoring help students to "fix" comprehension problems (Hofer, Yu, & Pintrich, 1998). Fixes for comprehension failures generally include help-seeking behaviors such as review of materials at hand, turning to a partner or teacher, or looking at examples. Karabenick and Knapp (1991) found that cognitive strategies such as elaboration were significantly positively correlated with help seeking, both informally (from their environment) and formally, from a peer or teacher. Although this study utilized self-report measures, it points to the idea that comprehension monitoring via self-questioning leads to help-seeking in an effort to fix misunderstanding.

Within inquiry learning ideally students monitor throughout the transformative processes; during orientation students check their understanding of the task, and the variables they find in the simulation. Students check their hypothesis with variable interactions they find in a simulation or model, and examine experimental output to see if it makes sense. Conclusions are examined against data-driven facts to see if they

make sense in relation to the investigated hypothesis or issue. Monitoring can also be seen from an organizational perspective, i.e., students need to keep track of their investigations and their artifacts such as data sets. In this way monitoring is a continual process of examining activity to ensure accurate comprehension and progress.

3.3. Evaluation

During the evaluation phase, students with solid self-regulative skill assess both the processes they employed and the products they create (Ertmer & Newby, 1996). Evaluation of learning processes involves any reflection on the quality of their planning, how well they executed their plan and how well they have executed goals. Evaluation of learning products involves student assessment of student created artifacts, such as lab reports, or data sets. Students can also evaluate their knowledge of cognition, that is, the concepts and facts learned during study, the strategies they used, and the conditions under which to employ those strategies and knowledge. It is within such activities that the semi-transformative nature of evaluation is seen, in that new knowledge is constructed and tied to student activity. Generally students evaluate by comparing how well their performance and learning fits with the goals and standards they have set during planning, similar to monitoring.

Within this dissertation, evaluation is considered to be what Schön (1991) distinguishes as "reflection-on-action" that is, at an activity *end-point*. Monitoring however is considered "reflection- in-action" that is, *during* the activity process. As De Vries (2004) states "Reflection-on-action is triggered by the need to recapitulate the process and product of an action"(p.22). Students take a proverbial step-back, as it were, and examine their efforts from the standpoint of the entire inquiry. As such student evaluative activity is often conducted at the end of a phase or cycle in this sense. Lab reports are the most common example of an evaluative activity and artifact that students conduct in science and inquiry learning.

3.4. Collaborative regulation

Most of the phases captured above point to the idea that regulation does not happen in isolation. If working alone, students are continually reacting to feedback from their learning environment as a means of promoting regulation. If working collaboratively, the presence of a teacher or peer also promotes regulation (Linn & Hsi, 2000; Lou, Abrami, & D'apollonia, 2001). Zimmerman (2000) states, "The social milieu influences self-reflection processes in a similar fashion to forethought and performance phase processes. Youths often form standards for self-evaluative judgments based on instruction, social feedback, and modeling from peers, parents, teachers, and coaches" (p.25). Thus the presence of a partner often promotes regulatory behavior (Lazonder, 2005; Teasley & Roschelle, 1993). Research essentially attributes the advantages of having

a peer for regulation to two factors: cognitive conflict, and interactive explanation building.

Partners who must make goals, check understanding, and evaluate outcomes together often come into conflict as to their ideas with regard to these activities. In this sense the presence of a partner "pushes" individual students to re-evaluate what they are doing and how they are thinking (Gijlers & De Jong, 2005; Patrick & Middleton, 2002). The resolution of these conflicts leads to partner construction of explanations and reciprocal teaching and learning behaviors (Ploetzner *et al.,* 1999). When co-constructing explanations students help each other clarify missing information. This has differing effects when individual student ability comes into play. In the case of a more knowledgeable peer, they benefit from explaining and reflection on their own knowledge; in the case of a less knowledgeable peer, they seem to benefit from the modeled explanation behavior, and receive on the spot assistance when they need it (Pressley et al., 1992). Although these interactions are advantageous, within technology-enhanced settings it also means additional challenges for the students in that they must also regulate the performance of their partner within the learning environment as well as their own.

Collaborative regulation models often take a cue from self-regulation models rather than being developed in isolation (Jackson, Mackenzie, & Hobfol, 2000). As such self-regulation models acknowledge a social component, without altering the essential processes of planning, monitoring, and evaluation. The work reported in this dissertation is no exception.

4. Student difficulties with inquiry learning

Together the phases depicted above capture what highly-self-regulated learners do. However self-regulative skill and its important outcome of "mindful engagement" (Land, 2000) are contingent upon prior cognitive structures and of course the environment and task resources students have at hand. Inquiry learning in and of itself is challenging, and student often have difficulty with both the transformative and regulative aspects of their investigations. As knowledge of these problems informed the design of specific regulative supports used in the studies, they are discussed below.

4.1. Orientation problems

"What in heaven's name must we do?" One participant in the experimental study depicted in chapter 4 lamented in her chat log when she first entered the technology-enhanced learning environment used for the research. A short but apt description to begin the difficulties students

have when orienting to an inquiry learning investigation. Students often enter an inquiry activity with insufficient prior knowledge which impacts their ability to effectively orient to a domain or problem (Gijlers, 2005). When students do access their prior knowledge it is often incomplete or inaccurate which interferes with making inferences about new knowledge they are trying to formulate (Land, 2000). This "situated learning paradox" occurs when students need meaningful information to engage in inquiry effectively, but have only everyday contexts and incomplete information from which to draw. "Although links to prior knowledge in everyday contexts may enhance the potential for transfer they also increase the likelihood that learners may draw on incomplete or inaccurate understanding, which forms the basis of faulty theories" (Land, 2000, p. 9).

If unfamiliarity with the domain is an issue, asking students to construct a model only exacerbates the problem. The creation of the model falls under what Jonassen (2000) calls a "design problem" in his continuum of well-structured to ill-structured problem types. Design problems are rather ill-structured in that they do not have a specific goal or answer as their main aim (Chi & Glaser, 1985), but an artifact, created often without clear standards, entailing the use of artificial (and often unfamiliar) symbol systems to structure and re-structure the problem representation. Thus during orientation, students may have not only prior-knowledge deficiencies, but also be unfamiliar with the task outcomes they are being asked to design. Familiarity of a problem type is one of the strongest predictors of success in studies of individual differences and problem solving ability (Sweller, 1988). Thus tasks, processes, and resources which are unfamiliar to students may impede proper orientation.

4.2. Hypotheses generation problems

Hypothesis generation is the cornerstone of inquiry learning. Students need to be able to specify possible relationships between variables in order to discover the truth value of the domains rules they are trying to investigate. When a modeling component is added to the inquiry setting, students express their hypothesis through their models, that is, every specification of a relationship between variables such as water outflow and tank diameter can be considered a hypothesis. This in some respects offsets one problem students often have with hypothesis; namely they often don't know what they should look like. Njoo and De Jong (1993) found that only 42% of student-generated hypotheses were syntactically correct and even less were correct from a domain perspective.

De Jong and Van Joolingen (1998) cite several studies in their review of problems students have with inquiry learning. Studies of Chinn and Brewer, (1993), Klahr and Dunbar, (1988), and Dunbar, (1993) all point to difficulties students have refining hypothesis based on data. Conversely inconsistent and unsystematic experimentation may lead students to

incorrect inferences within hypotheses which then change too frequently (cf., Kuhn, Schauble, & Garcia-Mila, 1992). Finally De Jong and Van Joolingen (1998) cite a prior work (Van Joolingen & De Jong, 1993) in which students only tested hypotheses which had the possibility of being confirmed rather than rejected.

4.3. Experimentation problems

As one can imagine, faulty hypotheses will lead to problems with the design of experiments. A quality experimental design, according to Klahr, Fay and Dunbar (1993), discriminates between hypotheses, is "trackable" in terms of its parsimony, and produces interpretable outcomes.

Unfortunately students often do not create experiments which truly discriminate hypothesis, they rely instead on designs which confirm rather than disprove suppositions, i.e., confirmation bias (De Jong & Van Joolingen, 1998; Dunbar, 1993; Quinn & Alessi, 1994). Furthermore students do not employ systematicity during experimentation which leads to outcomes which can't be interpreted. They often adopt a "guess and check" strategy or select variables which are inappropriate to test a stated hypothesis. Within simulations, De Jong and Van Joolingen (1998) state that students will not use the full breadth of possible experiments but restrict themselves to a small set. Finally De Jong and Van Joolingen found that students will often design experiments that are not meant to test a hypothesis but to generate a favorable outcome. In other words students will focus on an expected successful output instead of trying to understand the model they are working with. "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" (p. 185).

One reason students often fail to provide such well-organized data is because they inappropriately control variables. Lin and Lehman (1999) state that "control of variables refers to the ability of students to keep extraneous variables constant while investigating a factor or factors of interest" (p. 837). Kuhn et al., (2000) give one reason why. They argue that the control of variables strategy can not be understood unless students' mental model of causality itself is correct. "If we expect students to understand the operation of a multivariable system they must at least understand the concept of additive effects-effects that operate individually on a dependent variable but that are cumulative in their outcomes"(p. 500). They cite the fact that students often have difficulty with this and will instead formulate a "co-occurrence" model of causality in which students state that the mere presence of one variable's level and an outcome are sufficient for stating that the variable impacted the outcome.

De Jong and Van Joolingen's (1998) review also found student difficulties in data coding, and misinterpretation especially if analysis focused on

visual displays such as graphs and charts. Land (2000) discusses the cognitive operations which are often difficult for students using visual display information. In order to make accurate observations students must recognize whether changes in visual displays have occurred as a result of their own manipulations, discern which visual displays are important, and engage in causal reasoning and inference making to draw conclusions from their observations. However students often have perceptual difficulties particularly if they are novices with little domain understanding. According to Land, biased interpretations or the reinforcement of naïve concepts often result from these perceptual problems. Novices will often attend to surface features of the simulation and confuse visibility with relevance(Chi, Feltovich, & Glaser, 1981). Nor do they attend to the deeper logic of the visual information (Brungardt & Zollman, 1995).

4.4. Conclusion problems

Problems attending appropriately to data as illustrated by the visual display issues described above make it difficult for students to draw quality conclusions about their investigative efforts. But that is just part of the story, in part all the problems listed for the transformative processes would lead to difficulty forming appropriate conclusions. This relates to the fact that inquiry is a cyclical chain of reasoning to some extent. If a faulty hypothesis is generated which results in poor experimental design, any conclusions would naturally also contain problems. Confounding this chain of events even further, Students will often ignore, or reject data which is contrary to expectations, preferring instead to keep original hypotheses rather than adopting a new one. This may relate to the chain reaction described above or be related to students inability to come up with alternatives (De Jong & Van Joolingen, 1998).

4.5. Modeling problems

As modeling from a simulation plays a key role within the studies in this dissertation, this section will elaborate some issues students have with system dynamics modeling. System dynamic modeling is described briefly in section 2.2 of this chapter and in fuller detail in chapter 2, section 4.3. Sins (2006) discusses two types of problems with system dynamics modeling; conceptual and representational.

Conceptually students have trouble with dynamic phenomena and often display direct linear causal thinking (one cause to one effect) rather than the indirect feedback loop generated reasoning system dynamics promotes (Hogan & Thomas, 2001). In this instance students have difficulty seeing how a change in one variable in a system is passed along to all other linked variables, preferring to focus instead on a central relationship rather then a system effect. Students also have difficulty relating output from a model to the models they make. Hogan and Thomas (2001) found, for example, that students often used output

sparingly and only towards the end of their modeling session. Successful modelers in contrast use output more frequently, focusing on how the structure of the model impacts the behavior. Related to this is the fact that students often focus on individual variables and their specifications and don't understand that the model structure as a whole needs to be considered for a positive outcome (Doerr, 1996).

The second class of problems Sins (2006) discusses is the difficulty students have with the graphic nature of system dynamics formalism (i.e., what is a stock? what is an auxiliary?) and also with grouping similar entities to create model variables, and thus create non-parsimonious models (Shrader, Lindgren, & Sherin, 2000).

4.6. Regulative problems

To a large extent the literature on problems students have with managing their cognition during learning point to non-systematic working methods. De Jong and Van Joolingen (1998) concur in their description of problems students have in regulating their inquiry. Unsuccessful students will often work in random ways, that is, without a plan (Charney, Reder, & Kusbit, 1990; Veenman, Elshout, & Busato, 1994), pay less attention to data management, take less notes (Lavoie & Good, 1988), and record data less systematically than successful inquiry engaged students (Shute & Glaser, 1990). Related to monitoring, students have problems consistently performing self-regulation strategies such as self-questioning, and making judgments about their learning (2004). Problems within the transformative process of inquiry such as drawing appropriate conclusions certainly contribute to poor evaluation. This includes issues such as being able to evaluate results over the course of an inquiry, and making informed data-driven decisions about hypotheses.

A lack of knowledge of cognition about an inquiry task in general and effective inquiry strategies specifically, often confounds (especially novice) students' ability to properly regulate their inquiry efforts (Kuhn et al., 2000; Kuhn & Dean, 2005). For example, students often don't understand that the point of an inquiry task is to find causal links within a system, instead they might run experiments simply to create interesting outcomes (Keselman, 2003). This poor task understanding impedes students' ability to select appropriate strategies such as control of variables during inquiry learning. Selection of appropriate strategies is also impeded by a lack of knowledge about the how, why, where, and when to apply them. This meta-strategic functioning is an essential component to effective regulatory skill performance (Mayer, 1998).

This lack of metacognitive knowledge related to task and strategy selection during inquiry learning leads to dysfunctions in regulative skill attributed to "...ineffective forethought and performance control techniques" (Zimmerman, 2000, p. 26, 2001). Accordingly this lack of

goal structure promotes "reactive" methods of regulation. That is, students rely on social comparisons for their work rather than feedback generated from goals and tasks. When students find their social comparisons wanting, a cascade effect occurs, which can negatively impact the less cognitive aspects of regulation namely, a student's belief they can do the task (lowered self-efficacy) and their motivation. As such proper support for planning and monitoring may enhance regulatory behavior and assist in avoiding the problems outlined above. It does so because it may promote "pro-active" behaviors such as inquiry task understanding, proper control of variables, or identification of initial relationships which lead to success in inquiry learning.

5. Problem statement

Research on the use of technology-enhanced inquiry learning environments shows some positive effects on student learning outcomes, despite the difficulties outlined above. In particular students are thought to gain not only a deeper and more meaningful understanding of science domains but also valuable strategic knowledge which is applicable to problem solving in general (Njoo & De Jong, 1993). Deeper processing of a domain's knowledge and the strategies to support such learning depend however on factors such as existing cognitive structures, amount of attention and time spent in domain acquisition, and motivation (Gredler, 1997). It is here that an example of what both Carrol (1990) and Veenman (1993) call a "paradox of sense-making" occurs. Carrol states that when people are engaged in learning and using a tool they are highly motivated to do something meaningful, "Yet motivation to interact meaningfully in a situation is also at the root of a learning paradox: To be able to interact meaningfully, one must acquire relevant skills and understanding. But one can acquire these only through meaningful interaction" (Carroll, 1990, p. 73). Thus in order for learners to engage in an effective scientific inquiry they need to already posses the strategic knowledge which is inherent in a good scientific inquiry investigation (Kuhn et al., 2000). As research in technology-enhanced learning environments moves forward, so has a call to focus on the tools and design principles for student support in their pursuit of strong self-regulatory skills (Georghiades, 2000; Lin *et al.,* 1999). Inquiry learning is effective but students have to first learn how to regulate their inquiry.

The need to assist students with learning how to regulate their scientific investigations has resulted in the concept of scaffolds which help students to map and manage their psychological learning terrain. In classroom settings scaffolding is defined as actions taken by the teacher, or a more knowledgeable peer which assist learners in success with problems which would otherwise be too difficult (Quintana et al., 2004). This definition gave rise to its transfer to technology-enhanced environments in the form of cognitive tools as a means of scaffolding students, particularly in

environments designed for inquiry learning (De Jong, 2006b). Cognitive tools within technology-enhanced learning environments are meant to scaffold students in their modeling of the ideal steps for productive learning (Jonassen, 1999; Kommers, Jonassen, & Mayes, 1992). Jonassen, (1999) determined that cognitive tools could be designed to represent the domain, to model knowledge, and to assist in collaboration during learning. An example of domain representation might be a simulation that gives students a mental image with which to visualize and manipulate scientific processes. Students can model knowledge via a concept map tool, knowledge tree diagrams, or with more formal modeling formalisms such as with system dynamics applications like Stella. Collaboration tools include chat trees, or technical applications where shared knowledge can be accessed, manipulated and stored by groups.

Although there are different views as to what cognitive tools are, for the purposes of this dissertation, they are seen as transformative or regulative in function (cf., Clarebout & Elen, 2006). Cognitive tools for experimentation or data collection acts (such as a simulation, or a tool for student model construction) are examples of transformative, whereas regulative tools may illuminate important processes to learners, provide hints and reminders about their work, and promote reflection by eliciting student explanations and elaboration of their work (1994). Regulative scaffolds in this dissertation are also referred to as regulative supports.

Scaffolding of this sort has shown positive effects within science, math, and inquiry learning environments (Kramarski & Gutman, 2006; Veenman et al., 1994; Zhang *et al.,* 2004). Although compelling, these research studies often examined individual scaffolds for monitoring, or planning, but not both. The current research is concerned with scaffolds that promote all the regulative behaviors. In addition, the studies in this dissertation took a broad contextual view, as they were conducted in ecologically valid, diverse classroom settings, such as online synchronous non-face-to-face collaboration, face-to-face collaboration and individual use of regulative scaffolds. One general research question guided this dissertation:

What is the effect of regulative support on learning activities and outcomes during technology-enhanced inquiry learning with simulations and modeling?

6. Dissertation overview

Designing support for students follows the same process in many respects to the process of inquiry. First an exploration occurs following experimentation to determine specific aspects of support and then an iterative formative cycle is engaged from drawn conclusions. The series of

studies described in this dissertation follow the same pattern. Following a description of the learning environment in chapter 2, the first study in chapter 3 was conducted to explore how students regulated during scientific learning with minimal support. The study, depicted in chapter 4, built on the exploratory findings with the implementation of a regulative tool which supplied goal lists, and a note-taking facility for monitoring. Results from this study influenced the scaffold designs for the experimental study depicted in chapter 5. Supports were amended to include an inquiry cycle with sub-goals, note-taking facilities which included specific prompts and cues, and a report template scaffold for evaluation. As issues with consistent use of regulative scaffolds persisted throughout the studies, possibly due to the presence of a peer, the empirical work in chapter 6 turned to examine the impact collaborative versus individual use has on regulative scaffolds and learning outcomes. Finally chapter 7 presents conclusions drawn from these studies, with the aim of providing insight into regulative support design.

2. Situating the research: Co-Lab and its tools

Abstract

This chapter describes the technology-enhanced learning environment (Co-Lab) utilized for the research depicted in this dissertation. First the general design metaphor is discussed followed by a description of the interface and the cognitive tools which support the transformative processes of inquiry. The Process Coordinator (PC) is described as the regulative tool under investigation in the empirical chapters. Finally a summary of cognitive tools found in Co-Lab is given with a general conclusion.

"Hackworth was a programmer. Runcible was the program. It was made up of a number of subprograms, each of which had resided on a separate piece of paper until a few minutes ago, when the immensely powerful computer in Hackworth's office had compiled them into a single finished program written in a language the matter compiler could understand" (Stephenson, 1995, p.57).

1. Origins and development

Compilation of a variety of cognitive tools within an over-arching thematic structure naturally goes through a formative developmental trajectory. Co-Lab is the name of the program used by the students in the empirical chapters found in chapters 3 through 6. A new program at the beginning of this research; its development entailed navigational, user, interface, and cognitive tool integration work throughout the studies depicted within this dissertation. The original inception of Co-Lab was to develop a technology-enhanced learning environment for collaborative inquiry learning which incorporated simulations and the ability for students to construct system dynamics models of phenomena (Van Joolingen *et al.,* 2005).

This aim was met through two versions: an online collaboration version and a stand-alone version of Co-Lab in which students worked together face-to-face. The online collaboration version was used for the studies presented in chapters 3 and 4; the stand-alone version was used in the studies presented in chapters 5 and 6. Although different in how students collaborated, the Co-Lab interface, simulations, and other transformative cognitive tools remained the same. This chapter presents a general overview of Co-Lab and its tools to highlight the relevant architecture and *version commonalities* found in the studies. Specific aspects of the environment relevant to the methods of the research depicted such as; learner tasks, and regulative scaffold designs, are described within the empirical chapters.

2. A metaphor

In keeping with the constructivist view of allowing students to "think like a scientist", Co-Lab designers[2] set out to develop a virtual space which housed the relevant tools and scaffolds needed to explore and learn physics and biology topics. They accomplished this tool integration within a simple metaphor, that of a science complex with different buildings

[2] Co-Lab was developed as part of the European Union's School of Tomorrow Granting program under project number IST-2000-25035. Five European partners contributed to this project; The University of Twente and the University of Amsterdam (The Netherlands), The University of Murcia (Spain), IPN- Institute for Science Education, University of Kiel (Germany) and TEOS, Inc. (Italy).

containing multiple floors and rooms (see Figure 2-1). The entire metaphor seeks to organize inquiry learning by situating the students in the context where it is performed. It also seeks to act as a domain model wherein, buildings and floors constrain domain complexity. Buildings are restricted to cover specific science topics (i.e., courses) within overarching science domains such as physics or biology; whereas floors act as "modules" which constrain the level of topic complexity. That is, lower floors correspond to basic concepts and higher floors build on this knowledge while increasing the levels of topic complexity. Rooms on each floor provide a model of scientific thinking in their correspondence to the transformative scientific inquiry processes; orientation, hypotheses generation, experimentation, and drawing conclusions.

Within the studies presented students worked in two buildings. For introductory purposes they used the green house gases' building to orient to Co-Lab and gain experience with modeling prior to the empirical task[3]. For the experiments students conducted their activity within a water-management building, on the first (basic fluid dynamics module) floor. When students logged into a floor, four rooms became available. The rooms are the hall, the lab, the theory room, and the meeting room; each corresponding to a transformative inquiry process. Wherein orientation type activities occurred in the hall, hypothesis generation and experimentation occurred in the lab and to some extent in the theory

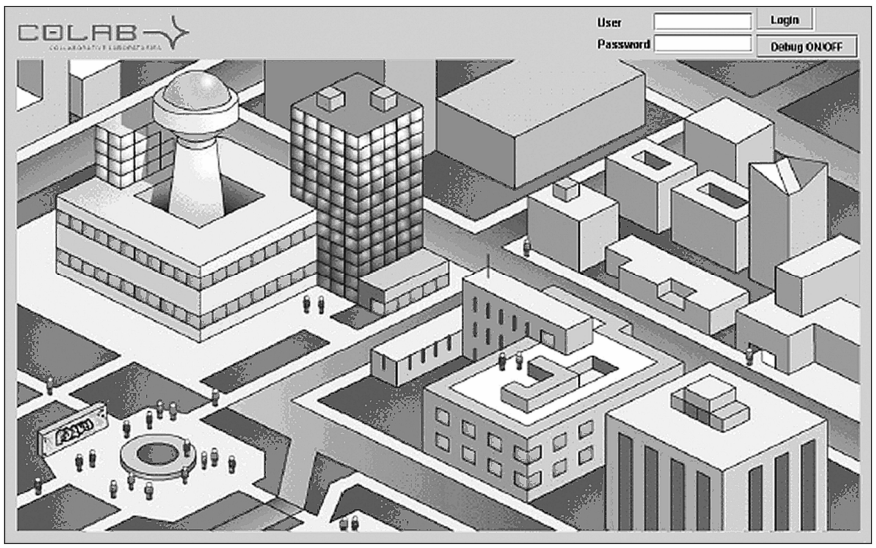


Figure 2-1. Co-Lab Login Screen

[3] In the studies presented in chapters 3 and 4 this building configuration was used, however in chapters 5 and 6 a model introduction floor within the water-management building was created. The modeling introduction is elucidated in more detail in the empirical chapters.

room, where students also built their models, and developed conclusions together within the meeting room. Cognitive tools specific to these activities existed in each room to assist students with their inquiry efforts. To aid with navigation, communication, and organization, Co-Lab's interface contained tools that were available across rooms.

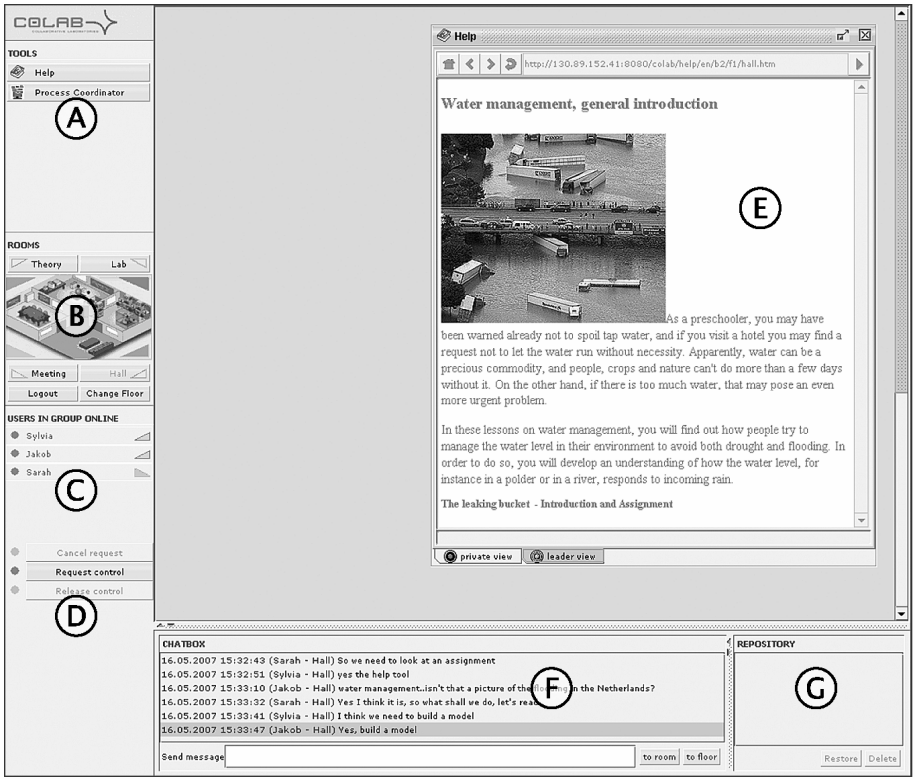
The following sections detail the interface and the cognitive tools specific to each room. Emphasis on the Process Coordinator (hereafter PC) is found in its own section, (5), due to its emphasis within the empirical chapters. A caveat to the following descriptions is their emphasis on the environment and tools *used in the empirical chapters*. Co-Lab housed different experimentation tools and covered domains other than that of this dissertation's research. An overview of Co-Lab in this perspective can be seen in Van Joolingen et al., (2005).

3. Co-Lab's interface

Figure 2-2 shows a screen shot of what student's see after logging into Co-Lab within the studies found in this dissertation. They enter the hall, which is described in the next section. The interface included affordances for student navigation, collaboration, and organization.

The navigational tools shown include the room-specific tool menu (A) and the navigator (B). The room-specific tool menu lists tools which are specific to a room (these are detailed in the following sections). Students move between these rooms with the navigator by clicking on the room name (i.e., hall, lab, theory, and meeting).

In the online collaboration version, students were supported in their group work with several tools. The locator (C) allowed a student to see which rooms their group members were in. Student negotiation of who used the tools at any given time was conducted with the control tool which is built-in to the locator as a traffic light; a green light indicated control, a yellow flashing light indicated a control request, and a red light indicated non-control. The necessity of this feature was due to interactive effects of multiple tool use with collaboration, (i.e., if two students run the simulation at the same time it would be difficult to come to a common understanding). The chat box (F) afforded student talks of the domain and their activities. In the research presented in chapters 3 and 4, students were forced to communicate through this tool. Besides being a requisite to affordance in online collaboration, writing in such a way encourages students to make their thoughts explicit, and promotes co-construction of explanations. Messages could be sent to a specific room, or all rooms. From an organizational perspective, group members could



Note. A- Room-specific tool menu, B-Navigator, C-Locator, D-Control, E-Help, F-Chat, G-Object Repository.

Figure 2-2. Hall in Co-Lab

keep track of their saved artifacts with the object repository (G). Here student work such as data sets, models, and ultimately lab reports were housed.

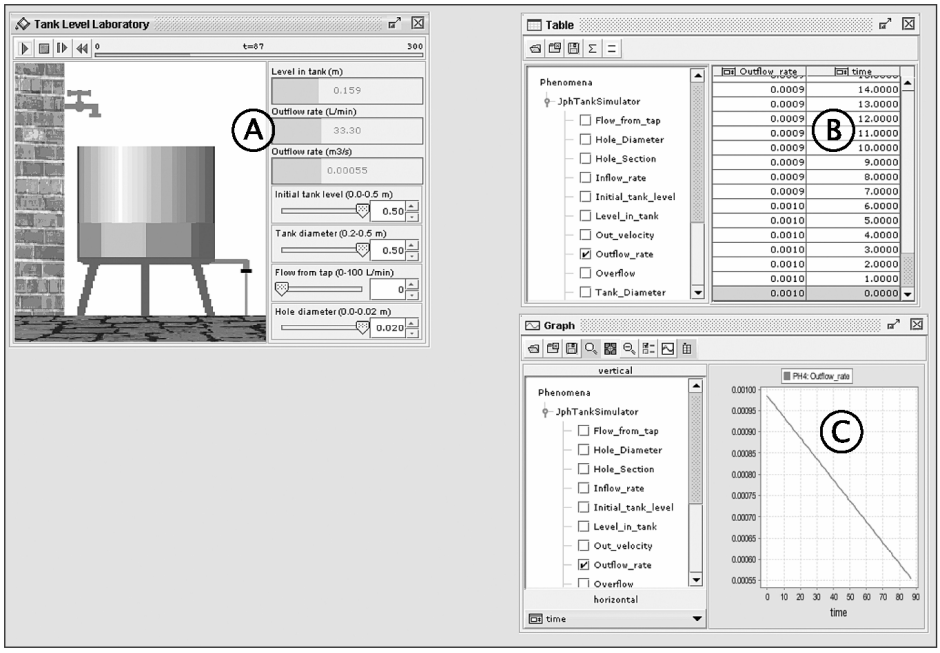
4. The cognitive tools, by room

4.1. The hall

Within the hall students orient to the science topic of their inquiry efforts. They can read the assignment with the help tool (see E in Figure 2-2) and use the PC. The help tool shows HTML documents which contain the assignment, background information, and technical information for the operation of tools. The PC tool (not shown in Figure 2-2) will be discussed in more detail in section 5.

4.2. The lab

The lab room houses tools students within the empirical chapters used to conduct experiments (see Figure 2-3). The room-specific tools available in the studies found in this dissertation were a simulation, a graph and a



Note. A- Water tank simulation, B-Table, C-Graph.

Figure 2-3. Lab work space and tools

table tool. The water tank simulation (A) allowed students to change the properties of the tank in their experiments. They could change; water level, flow from the tap, tank diameter, and drainage pipe diameter. The table (B) and graph (C) tools assisted students with data analysis. Different variables could be selected from lists shown in the left pane of the tools. Their corresponding output appeared in the right pane. Data sets could be saved and opened to compare with other data-sets from multiple experimental runs.

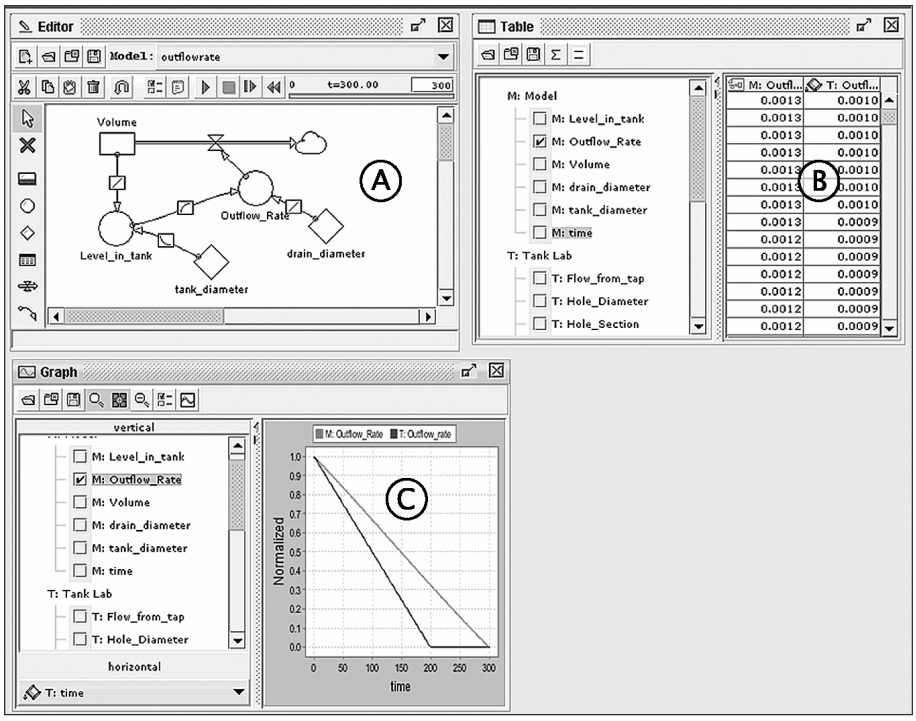
4.3. The theory room

The theory room is where students construct system dynamics models. Figure 2-4 shows the model editor, and the table and graph. The table and graph operate the same as they do in the lab room. They allow students to compare data run from the water tank simulation to data run from their models. The model shown is the target model students were expected to attain during the experimental studies found in chapters 4 through 6. As modeling is very new and quite difficult for the students, they did an introduction to system dynamics modeling prior to the experimental task in a non-science related domain. This introduction is elaborated in the empirical chapters.

The modeling approach used in Co-Lab is system dynamics modeling. Dr. J. Forrester developed system dynamics modeling in the 1950s, while at the Massachusetts Institute of Technology and while working with General Electric (Forrester, 1961). The goal was to develop a way to simulate "systems", social, organizational, and scientific, and how they worked over time, such that the relationships and inter-relationships are clarified towards solving system related problems and gaining insight into behaviors of variables. Van Joolingen et al., (2005) state with regard to this important modeling formalism:

"When reasoning about the continuous physical systems found in water management [...] system dynamics modeling appears to be the most appropriate to represent these systems. Such models reflect the dynamic nature of physical systems, by allowing simulation, envisioning the consequences of all direct and indirect relationships between variables in a time-dependent system. The use of generic variable types such as stocks, constants, and auxiliaries provide learners with 'mini-mental models' of how to think about variables and their relationships in the system" (p.679).

Modeling in Co-Lab is meant to work in conjunction with the simulation found in the lab. As shown in Figure 2-4, data from a model can be compared with data from the water tank simulation. This is shown when



Note. A- Model editor, B-Table, C-Graph.

Figure 2-4.Theory room work space and tools

students select the same variable from the model as from the simulation within the table and graph tools. This serves the purpose of "calibrating" the model, that is, making sure it produces the same results as the simulation. This indicates to students whether model structure and variable relationships are sound.

One important feature of the model editor is the capacity students have to specify variables qualitatively or quantitatively. Figure 2-5 depicts the qualitative relationship between tank diameter and water level; If tank diameter is larger, then water level is smaller. In contrast the variable "outflow rate" is shown specified as the mathematical formula "drain-diameter * (1-exp (water_level))".

The affordance of qualitative modeling is thought to aid the conceptual problems of students during model-construction (see chapter 1, section 4.5). Specifically, it allows them to focus on simple representations of variable relationships while obtaining overall model structure whereas quantitative specification can be done at a later stage of model refinement. This is thought to promote the successful modeling behavior of focusing on how the structure of the model impacts its output before refinement of variable relationships occurs. Within the empirical chapters students were asked to construct qualitatively specified models in the experimental task (although students were often found to specify parts of their model quantitatively).

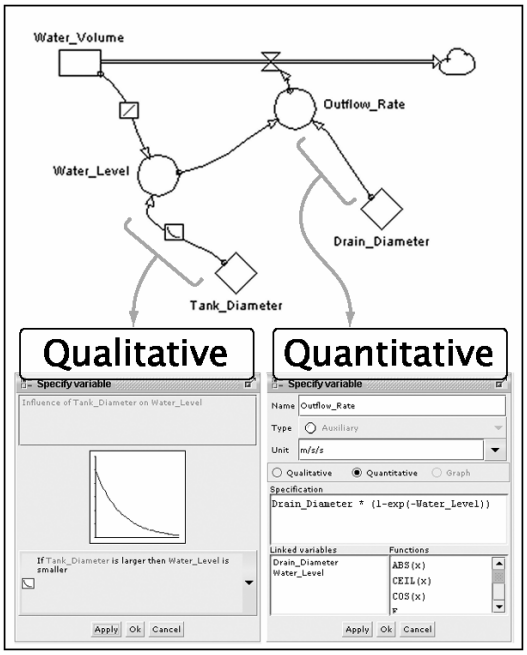
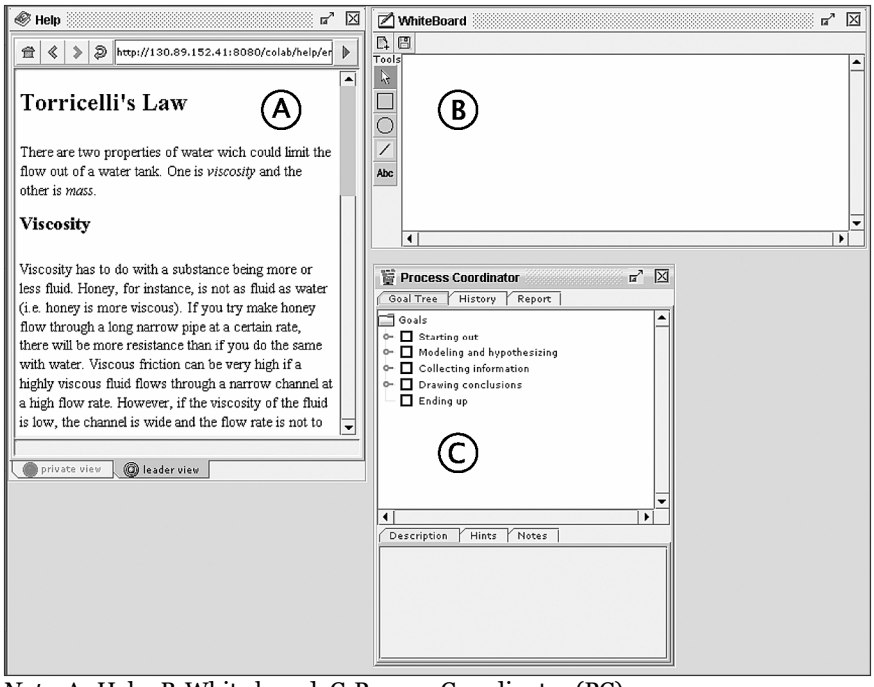


Figure 2-5. Qualitative and Quantitative Model Specification

4.4. The meeting room

The meeting room's tools promoted regulation of students' thinking. Shown in Figure 2-6, this is where students were expected to form conclusions, plan their inquiry, make notes, and write evaluative lab reports. The room-specific tools included the help tool (A) a whiteboard (B) the PC (C), and the report editor (housed within the PC initially). Also included in the meeting room were the data analysis tools; the table and graph (not shown in Figure 2-6).

The whiteboard (B) assisted students with communal representation of model sketches and ideas, without having to work out the system dynamics first. The help tool (A) contained all help files found in the environment besides the meeting room-specific HTML documents. (In all other rooms, help files are room-specific). The table and graph were also available for students to consult saved data-sets during report writing. Students wrote reports with the report editor, a simple text-editor tool. This tool was accessed from the PC for the study depicted in chapter 4, but it was a separate tool for the studies found in chapters 5 and 6. In the first study depicted in chapter 3 the PC was only housed in this room. This tool assists students with the regulative processes discussed in chapter 1. Due to its emphasis in the empirical chapters it is described in its own section below.



Note. A- Help, B-White board, C-Process Coordinator (PC).

Figure 2-6. Meeting room workspace with tools

5. The Process Coordinator (PC)

Although several different versions of the PC were used across the studies, and excluding control condition versions of the PC (elaborated within the empirical chapters) the cognitive tools had several common features. Figure 2-7 shows the initial configuration of the PC in the exploratory study reported in chapter 3. Further modifications of the PC to address results of the successive empirical research reported, are described in detail within chapters 4 through 6.

The "taking off point" for use of the PC was to select a goal or sub-goal. This assisted students in the first phase of self-regulation: planning. Once a goal was selected students could view a goal description, or hints. Hints gave students references to help files, and strategy suggestions, such as how to control for variables during experimentation. Students were supported in monitoring their endeavors with a note feature. A process view, called the "history" gave them a sequential record of their notes which could be copied directly to students' reports. The report feature contained a template[4] which gave section headers and content suggestions students could use to evaluate their inquiry work.

6. Conclusion

Collectively the tools described above made up the support system developed for students within Co-Lab. For convenience an overview of the tools covered in this chapter and a brief description with corresponding room and study information is listed in Table 2-1 and
Table 2-2.

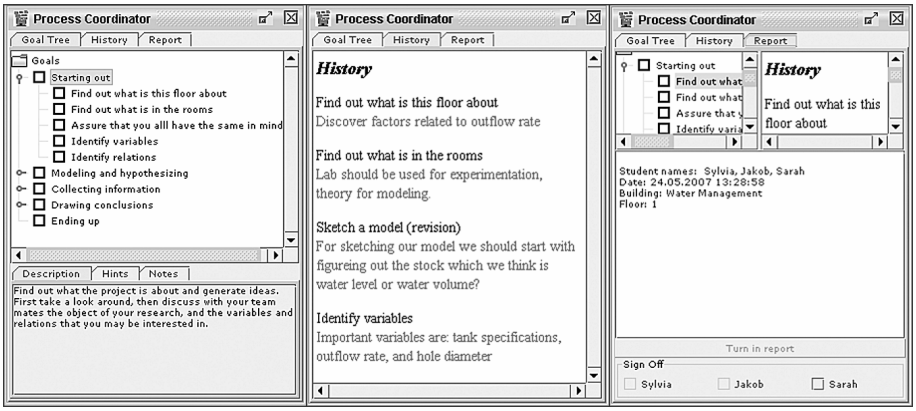


Figure 2-7. PC with tabbed views; (from left) Goal Tree, History, and Report

[4] This template was moved to the help tool as a help file in studies depicted in chapters 5 and 6.

Table 2-1. Co-Lab interface tools

Interface tools	Function
Chat[a]	Synchronous text communication with group-mates
Control[a]	Request operational control of tools
Locator[a]	List of group-mates with room tracking
Navigator	Room changes
Object Repository[b]	House saved student artifacts (i.e. models and data-sets)
Tool Menu	Room-specific tool list

a. These online collaborative tools were only available in the studies reported in chapters 3 and 4. With the stand-alone version of Co-Lab students collaborated face-to-face. b. The object repository is only available in the studies reported in chapters 3 and 4, in the stand-alone version of Co-Lab (chapter 5 and 6) objects were saved to individual tools.

Table 2-2. Room-specific tools

Room-specific tools	Function	Room
Help	HTML text material and help files	all[a]
Model Editor	Construct system dynamics models	theory
Process Coordinator (PC)[b]	Planning, monitoring, and evaluation	meeting/All rooms
Report Editor[c]	Text editor for lab reports	meeting
Table and Graph	Data analysis and view data sets	lab, meeting, theory
Water tank simulation	Simulation of a water flow for experimentation	lab
White board[d]	Collaborative model sketches	meeting

a. Help files are room-specific. b. The PC was placed only in the meeting room in the study found in chapters 3, thereafter (chapters 4-6) it was available in all rooms. c. Due to technical and design issues, the report editor was utilized only in the studies described in chapters 5 and 6. d. The whiteboard was only available in the studies found in chapter 3 and 4.

As Bera and Liu (2006) say so eloquently, "In a design scheme where the tools are the navigation, these tools are designed to support cognitive processes" (p.297). Processes such as those found in conducting a quality inquiry; where students explore and experiment with science phenomena. In turn the tools depicted seek to help students gain valuable critical thinking skills as well as science knowledge. From an instructional design perspective, the development of regulative tools is the focus of this research. Research conducted with an eye for "the formative detail".

That is, refinement of regulative features specifically over the course of experiments *with* the students they were built for. In the studies

following, the focus is on how perceptions derived from student usage of regulative scaffolds can be used to benefit regulative support design. As a starting point, the first exploratory study examines how students regulate in a naturalistic setting, with virtually no regulative support available. The results of this research are documented in the next chapter.

3. Exploring task approach, collaboration, and regulative patterns[5]

Abstract

This study examined how high-school students regulate their learning within Co-Lab: a technology-enhanced environment designed to promote inquiry learning. Regulation of inquiry learning, as defined by Njoo and De Jong (1993) includes two basic processes, planning and monitoring. Unraveling self-regulation of students within such learning environments is further exacerbated by collaboration and features of the environment. This study sought to identify how students (N=21) collaboratively planned and monitored within a two-hour inquiry learning session. Ultimately the goal of this study was to provide recommendations for the design of Co-Lab and its tools in order to optimize support for self-regulation in areas where students need it.

[5] This chapter was adapted from Manlove, S., & Lazonder, A. (2004). *Self-regulation and collaboration in a discovery learning environment*. Paper presented at the First Meeting of the EARLI-SIG on Metacognition, June 30 - July 2, Amsterdam, The Netherlands.

"Because of the way the ractive was hooked up, she didn't get direct feedback from her counterpart on the other end. She assumed it was a little girl. But she couldn't hear the girl's voice. Miranda was presented with screens of text to read, and she read them. But she could tell that this process of probing and focusing was being directed by the girl" (Stephenson, 1995, p. 120).

1. Introduction

Inquiry learning's question-driven and activity-focused emphasis describes how students read text material, handle lab equipment, collect data, and write reports of their results based on experimentation and forming conclusions. Simulations, data analysis, modeling tools, domain and help files afford the transformative processes of inquiry in technology-enhanced learning settings. All of these tools could be taken from the scientific world into the virtual one to support their enactment. Less clear and harder to capture from authentic scientific practice is how to afford students the means to check their progress and understanding in a goal directed manner.

During learning, enactment of regulative processes such as planning, monitoring, and evaluation are dependent on students' domain knowledge and abilities naturally, but regulative skill enactment also depends on the contextual features of the environment where students conduct their work (Choi & Hannafin, 1995; Dillenbourg, 1996; Pintrich, 2000) Regulative behavior is in fact particularly sensitive to influences from the setting in which it is enacted, in that aspects within the setting trigger it to occur. In classroom learning settings, teacher-student, or peer-peer interactions intuitively incorporate regulation through their conversations via help-seeking, questions, and explanations. The presence of a teacher and peer in this sense has the advantage of immediacy and flexibility, giving students what they need when they need it (Azevedo *et al.,* 2005; Lazonder, 2005). Within technology-enhanced learning environments *cognitive tools,* meant to provide regulative support, attempt to mimic the processes students need "…to succeed in problems that would otherwise be too difficult" (Quintana et al., 2004, p. 338).

Van Berkum and De Jong (1991) and Swaak (1998) frame the challenge of effective cognitive tool design as being its proper placement on two bi-dimensional scales: directive to non-directive and obligatory to non-obligatory. Directive support is characterized as prescriptive and learning is stimulated directly (i.e., through questions, advice, or direct guidance). Non-directive support *provides favorable conditions* by taking away potential obstacles (i.e., only allowing certain actions on the part of the student to constrain the domain until mastery is reached). The simulations and room-specific activity restrictions within Co-Lab are further examples of non-directive support which help to focus students on important information. Concurrently, the amount students feel obliged to

use the support (i.e., freezing an environment until a note is made) versus their freedom to choose when and where they need help also comes into play.

For regulative (and transformative) tool support to be effective, a balance must be struck on these scales. Loosely defined it is a balance of being just directive enough, without interfering with the learning process. A study of Schworm and Renkl (2002) articulate this balance. In a 2x2 factorial design experiment they investigated the influence of instructional explanations and prompts on learning within an interactive learning environment. Results showed that a combination of prompting students to explain *and* provision of instructional explanations may reduce student self-explanations (a monitoring strategy) because they felt forced to split their attention between comprehension of the domain and making their own explanations. (For a review of these studies see Aleven *et al.,* 2003). Lan (2005) also discusses how forcing students to use support which represents strategies students are unfamiliar with may increase the cognitive burden students feel between understanding domain issues and regulation of their behavior. An approach to avoiding this issue is to tailor regulative support to the nature of student difficulties and behaviors.

Co-Lab's design metaphor of a science complex with buildings and floors is ideally suited for this investigation. Its design can be characterized as one which "provides favorable conditions" by preventing obstacles through domain and room-specific activity restriction. Navigation between the four virtual rooms provides insight as to where students spend their time, and on what activities, from which productive working patterns can be described.

Specifically for regulative support, particular attention should be paid to the regulative behavior students' show within their navigational patterns, and their discussions. For example, tool use combined with interaction data can show if students understand the activity or need to re-check it, make plans together, adopt a primarily cooperative working method, or query each other with comprehension-checking questions. These working methods can also be compared to students' learning products and progress on the task to shed further light on how students should be supported. This ecologically valid method examines students' experiences transactionally in the learning environment (Salomon, 1996) so support can find its proper placement on the dimensional scales (non-directive; non-obligatory to directive-obligatory).

Three questions guided this study:

1. How do students approach the learning task as evidenced by their navigational patterns within the environment?

2. How are students regulating their learning task, and collaborative partnerships?

3. What problems are in evidence from the navigational patterns and student conversations?

2. Method

2.1. Participants

Thirty-nine students from higher-secondary education, aged 15 to 17, participated in this study. The students came from a nature and technology track, the curricula emphasized science and technology. The participants worked in groups of 3, which resulted in 13 triads randomly assigned by the experimenter. Teacher reviews of group formation were undertaken to check their compatibility to work in groups. Due to technical difficulties with the Co-Lab environment during the experiment, of the 13 groups which participated only seven were able to use Co-Lab for between an hour to two hours. These seven groups form the basis of this analysis.

2.2. Materials

Co-Lab was installed on a local server and was accessed through a local area network. Table 3-1 shows the room-specific and interface tools available; a detailed explanation of these tools is presented in chapter 2. Two modules were implemented from Co-Lab's green house gasses and water-management buildings. The goals and purposes of these modules are explained briefly in the procedure sections below. In addition to the tools specified above, Co-Lab was setup with materials for the students to

Table 3-1. Overview of operational tools and their location

Meeting	Lab	Theory	Hall	Interface
PC	Simulation	Model editor	Help	Navigator
Whiteboard	Table	Table		Chat
Help	Graph	Graph		Control tool
	Help	Help		Object Repository Locator

Note. PC denotes Process Coordinator.

use during the experiment. The greenhouse gas building was setup with a preset model for the students to explore and use during both the introduction to Co-Lab and the modeling introduction. An assignment for the water management building was also specified. Finally, minimal regulative support was provided by the Process Coordinator tool

(hereafter PC). The PC was setup with a list of top level goals: (1) Before you begin, (2) Modelling and hypothesizing, (3) Data collection, (4) Drawing conclusions and (5) Evaluation. The PC was setup with top level goals to prevent a lack of focus on the part of students. This lack of focus was considered a danger due to the complexity of both the environment and the task.

3. Procedure

At the beginning of the experimental sessions, students were put into triads. In their triads they were introduced to Co-Lab. Observers, each seated with one triad around one computer, used a checklist to provide a 20 minute "guided walk-through" of Co-Lab. This walk-through directed a student to actions such as; login, navigation, collaborative features, and tool use. After the introduction students were directed to work individually on a 40 minute introduction to modeling.

This introduction was deemed necessary to control for difficulties students might experience with the use of the model editor and system dynamics modeling. Students worked alone, at their own computers within the green-house gasses building. They used a text-based packet that explained system dynamics modeling language and symbols as well as the use of the model editor in Co-Lab. In a step-wise manner, students built a model and learned concepts such as the various variables types (constant, auxiliary, flow, and stock) and their meanings.

Once the modeling introduction was completed, students took a short break. After the break they began the experimental task and worked together in the online collaborative version of Co-Lab. They were each seated at their own computers away from each other to minimize opportunities for face-to-face interactions and ensure use of the chat tool for communication. They were directed to begin by reading the assignment housed in the hall's help tool. The assignment began with a brief introduction to water management to contextualize the physics topic of fluid dynamics within recent flooding incidents in the Netherlands. It continued by providing a metaphor for basic fluid dynamic processes: a container that catches rain from a drain-pipe. A tap at the bottom of the container allows water to drain out and water flows into the container from a house drain pipe. This metaphor introduced them to the water tank simulation (see Figure 1-1). Specifically students were told to work with the simulation until equilibrium between the inflow and outflow of

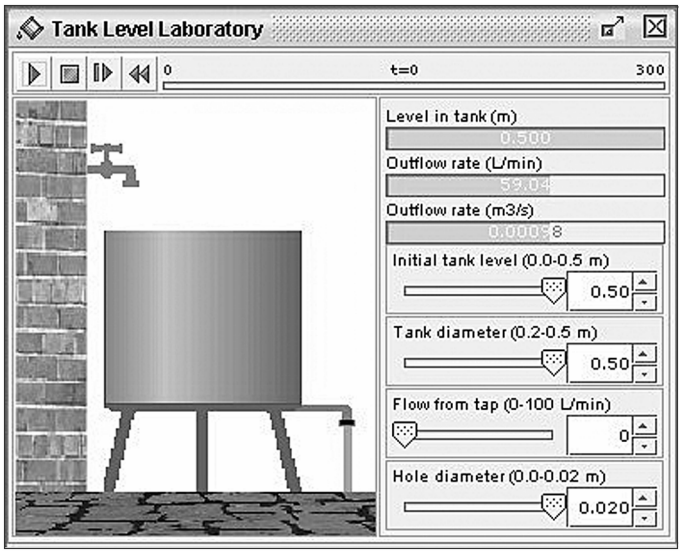


Figure 3-1. Water tank simulation

the tank was reached, and then to construct a model of this phenomena using the model editor. Students were pointed to the PC tool as a first step in planning their inquiry.

4. Measures

4.1. Log files

Log files of student actions use were used as the primary data source for student actions and tool use within Co-Lab. A log file sample is shown in Table 3-2. Prior to the data analysis, these log files were examined and a coding framework was established that showed which log file codes matched which student actions. A filtering program was created which allowed the raw logs to be brought into Excel for analysis. Refined filters to search the logs for specific combinations of actions were also created.

Table 3-2. Sample log file

grp	rm	time	user	name	sender	VT	variable	value
4	3	11:24:04	Mark	changeLocation	broker			
4	3	11:24:21	Bob	chatmessage	ChatTree			
4	3	11:24:25	Anne	setValue	environment		Flow_tap	100.0
4	3	11:24:25	Anne	VisualToolEvent	TankLab	Change		
4	3	11:24:26	Anne	setValue	environment		Flow_ tap	97.0

This log sample shows group 4, in room 3 (the lab room). It also shows the time of the action, the user login, or the student performing the action.

The name, sender, and VT fields denote the type of system action, specific tool, and type of action conducted by the student. To illustrate with the last three lines from Table 3-2, Anne sets the value (name) to change (VT) the Flow_tap variable in the tank-Lab simulation (sender) from 100.0 to 97.0 ml/sec. (value). Note that Table 3-2 does not show all the fields which are included in a full log.

4.2. Working patterns and regulative activity

To provide a "picture" of how students work together and regulate within Co-Lab, particular attention was paid to the room-use patterns of the students. Specific patterns of room changes were constructed using the "Name", "Room", and "Date" fields as indicators in the logs to calculate durations of time group members spent in a particular room. To examine collaborative behavior of students, individual group movements were recorded and consolidated for comparison. Specific tool use was also examined when it was deemed fruitful for the analysis and purposes of this study. For example, help tool use was examined to inform regulative activities such as re-visiting the assignment in the hall. The PC use and actions were examined, for example, only if durations of stay in the meeting room (where the PC was housed) were above 1 minute.

4.3. Regulative communication

Coding of the chat files followed a stepwise bottom-up approach. First the basic unit of analysis was determined by segmenting chat files into utterances. An utterance was defined as a collection of words with a single communicative function (Van Boxtel, Linden, & Kanselaar, 2000). Utterances are separated by a "perceptible pause" which in case of chat communication often comes down to sending the message. Each utterance was then classified according to its function in the dialogue. Here a distinction was made between cognitive, regulative, affective, procedural, and off-task utterances.

Next, conceptually related utterances were merged into episodes. Consistent with Van Boxtel et al., (2000) an episode was operationally defined as a set of expressions that is meaningful at the content level. As this study sought to identify which regulatory processes students spontaneously adopt, only the regulatory utterances were grouped into episodes with a distinction between regulation of the collaboration and regulation of the learning task as the two main categories. The same coding procedure was used in the study presented in chapter 4, where inter-rater agreement for segmentation reached 90% for the utterances and 68% for episodes; agreement estimates (Cohen's Kappa) for the classification of utterances and episodes were .65 and .95 respectively.

5. Results

5.1. Navigation

In Co-Lab, students have to move across rooms to perform learning activities. Table 3-3 shows the average frequency of room visits. Judging by these scores, the lab room was the most popular place to be, while the meeting room was visited the least. On average, the groups went to this room less than two times. This pattern was maintained when looking at the relative length of stay per room in Table 3-3. On average, the groups spent 83% of their time in the lab and theory room. The length of stay in the hall was approximately 16%, leaving a mere 1% of time for the meeting room.

Table 3-3 shows how navigation and room visits differed across groups. Considerable deviations were observed in the hall. Group 2 went there 21 times and spent over one third of their time in that room. Re-visiting the hall after the initial login might indicate students re-grouping, or checking the assignment for information. The latter claim was not supported by Group 2's chat logs and Help tool use. Groups 3 and 10, in contrast, spent the lowest amount of time in the hall. An examination of their help tool use in conjunction with the chat shows that in their initial visit they spent time discussing the assignment and subsequent chat logs reveal that both groups understood the assignment sufficiently to continue with the activity without going back for information or to check understanding.

Deviations from the general group pattern were also observed in the theory room. Group 1 had a low frequency count for theory room

Table 3-3. Number of room visits and length of stay per group

	Number of visits				Relative length of stay (%)			
	Hall	Lab	Theory	Meeting	Hall	Lab	Theory	Meeting
Group 1	8	11	6	0	18.3	39.2	42.4	0.0
Group 2	21	19	14	6	35.6	58.2	5.3	1.0
Group 3	5	13	11	3	4.5	41.2	54.0	0.3
Group 4	6	16	14	3	17.5	54.3	27.8	0.5
Group 6	9	11	4	3	15.5	82.6	1.7	0.2
Group 8	8	22	21	5	15.6	60.4	23.9	0.1
Group 10	7	11	14	8	4.2	35.0	56.1	4.7

Note. For reasons to be explained below, scores indicating room visits are calculated by adding the scores of individual group members. Time is the ratio of the mean time spent in a room for all group members to the total time spent in the environment.

visitation, but spent 42.4% of their total time there. Together these findings imply that this group rarely left the room and concentrated on modeling for a long time. Groups 2 and 6 spent the least amount of time in the theory room –yet for different reasons. Group 6 was unable to attain equilibrium in the water tank simulation despite often detailed and diligent work in the Lab. Thus they felt no real reason to visit the theory room because they had nothing to model. Group 2 *did* attain equilibrium in the tank, but somehow missed out on the second part of the assignment, namely to model the tank. Their incomplete understanding of the task may have been due to the fact that this group was by far the least focused on the learning task of all the groups having the highest percentage of off-task communication (see next section for further discussion). This could also explain why these students showed a relatively high number of visits to the theory room: they purposeless wandered around.

The meeting room had the lowest number of visits of all the rooms. Two groups stand out from this, namely Group 1 and Group 10. Group 1 did not visit the meeting room at all. Their chat logs suggest that they preferred to "get busy" rather than come up with a plan. After reading the assignment there is one instance where a student asks where the PC tool is, but this comment seems to be "lost" in the chat as it was not responded to by the other students (see Excerpt 1). Instead the students seem to plan directly from the assignment by drawing the conclusion that they need to adjust the parameters of the simulation first and all decide to go to the lab room. This may indicate that the students did not see any immediate need to plan using the PC or visit the meeting room. Group 10 had the highest number of visits and the highest percentage of time spent in the meeting room. This group was the only group which showed attempts at planning using the PC and showed a higher instance of discussing their overall approach to the learning task.

Excerpt 1

1	Frank	where is the Process Coordinator again?
2	Odette	hang on I'll ask
3	Romy	right, you do that
4	Frank	so we should enter the correct parameters in the simulation variables
5	Frank	…
6	Frank	well..?
7	Odette	all right
8	Romy	ummm yeah…you stay in control then
9	Odette	are we going to the lab now??
10	Frank	we are going to the lab

In addition to information concerning the students' stay in rooms, it is also interesting to examine how they move across rooms. As can be seen

from Figure 3-2 almost 80% of the room changes took place between the hall, lab, and theory room. The meeting room was a relatively isolated place, as it was involved in 22% of the room changes. This means that students went to the meeting room on 11% of the occasions.

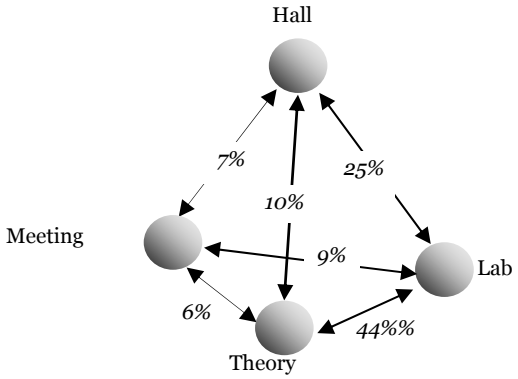


Figure 3-2. Room change patterns

5.2. Collaboration

Figure 3-3 gives a more detailed overview of the room changes. Being a sequential representation, it also illustrates how the groups organized their learning process. Two impressions can be drawn from these bar charts. The first concerns the groups' working pattern, that is whether the groups worked together (collaborative) or apart (cooperative). The second is an overall impression of how groups approached the learning task while working with Co-Lab.

A visual inspection of the bar charts in Figure 3-3 reveals that in general the groups' working pattern was fairly collaborative meaning they stayed together in their rooms and attempted to work together. However, Groups 2, 4, and 8 show evidence of deviations from the collaborative pattern. Their chat files were examined to check whether or not students made a conscious decision to work in separate rooms.

Group 2 showed a tendency to work apart during the later stages of their session. As their chat files contained only one instance of assigning tasks which explains room changing, it seems fair to conclude that this group did not work collaboratively during the latter part of their session. Group 8 showed a similar deviation from collaborative work patterns at the end of their session. Following a group move from the lab to the theory room, the second student takes control and begins modeling. Student 1 and 3 stay a bit, then agree to return to the lab to make a graph and announce their decision. The second student continues modeling for approximately ten minutes before joining the others in the lab room. She then returns to the theory room and actually goes to the meeting room, (not shown in

Figure 3-3 due to the short duration), but there is no announcement or agreement with the other students regarding these room changes. Student 3 follows her in, leaving student 1 behind in the lab room. Again no explicit agreement or statement is made about this.

The first group member in Group 4 tended to deviate from the collaborative pattern throughout almost the entire session. Most deviations occurred between the lab and theory room, and the chat revealed very few instances of agreed upon room changes. In fact only two instances seem to be derived from stated actions which imply room changes.

5.3. Approach to the learning task

The room change patterns from Figure 3-3 also provide insight into the different approaches groups took to the learning task. Two approaches were identified with some deviations from these patterns. These approaches were labeled "exploratory" and "sequential" and are described in the section below.

Explorative groups

The majority of groups can be classified as explorative. Groups, 1, 4, 8, and 10 approached Co-Lab and the task with initial work in the lab, moved to the theory room briefly, then returned to the lab to conclude their session with significant time spent on model work. Before their initial visit to the theory room to begin model work, the logs indicate that these groups achieved equilibrium with the water tank simulation. The structure of the lab work these groups engaged in doesn't reveal any systematic experimentation based on formal hypothesis making. Rather the groups tended to explore the simulation with runs to see the effect of variables and then "intuiting" variables changes. Further simulation runs show a "hit or miss" approach in just trying to change inflow and hole-diameter until equilibrium was attained.

In their initial theory room visits prior to returning to the lab, these groups tended to explore the model editor. They then returned to the lab to gather more information such as variable names, and types (i.e., stocks, auxiliaries, etc.) and settings before continuing model work. A good example of this is found in Excerpt 2 (see page 43). This shows a chat excerpt from Group 4. Fred is in the lab looking at settings in the table in order to identify variables to use in the model. His reference at the end of "making a theory" is a reference to their model work in the theory room.

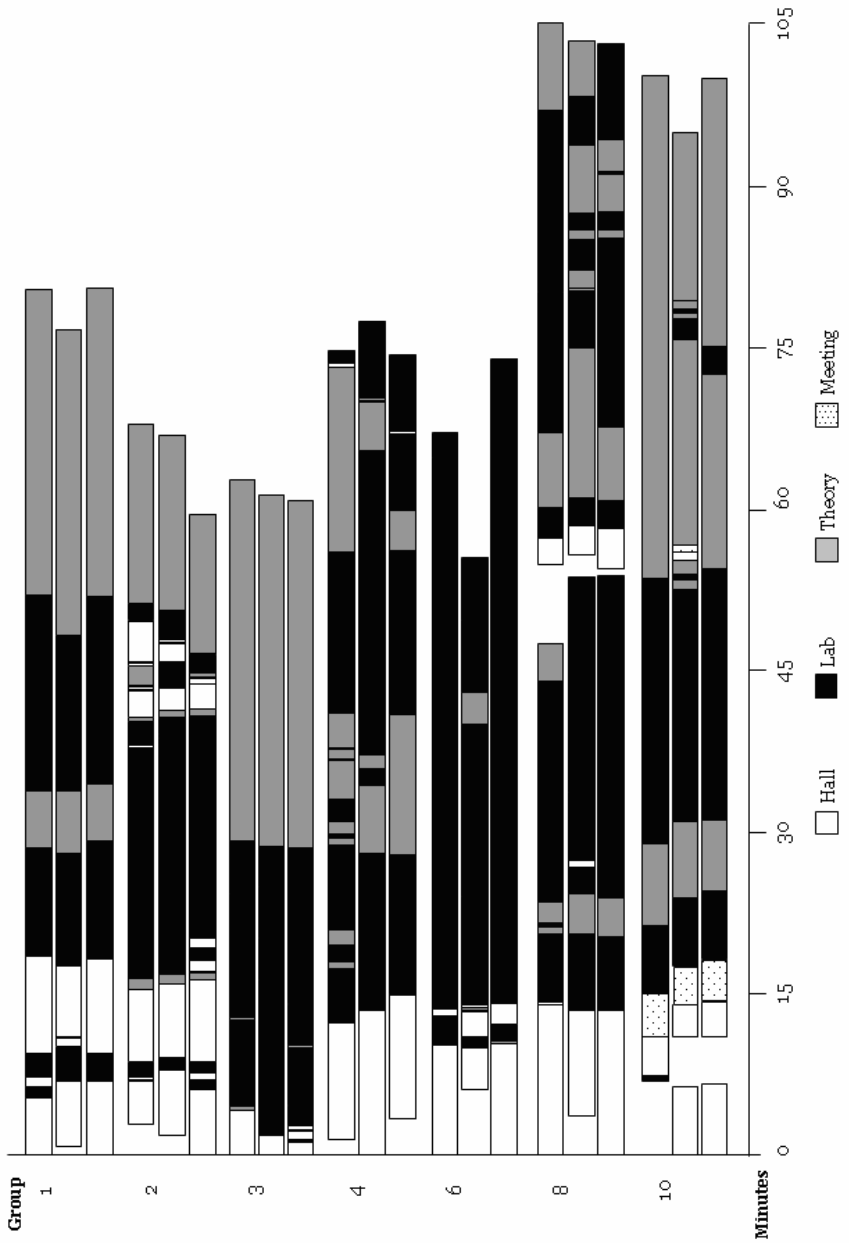


Figure 3-3. Room patterns by group

Excerpt 2

1	Fred	I have to copy the variables.
2	Fred	I am copying the variables
3	Fred	Do you see the table now?
4	Fred	That is level in the tank
5	Fred	thus the capacity
6	Fred	See it almost always stays the same.
7	Fred	Is it possible for us to consider that a constant?
8	Fred	I have found two other settings
9	Fred	So now we go to make a theory.

In the final phases of model work, all of these groups had *model fragments* in various states and most made an attempt at running their models. By model fragments it is meant that students used all the types of variables (stock, flow, auxiliary, and constant) and had drawn relationships between them. With the notable exception of Group 4, all groups specified names of variables and attempted some variable settings. Group 4 only attempted to label one variable in their model. Group 10 was the only group which attempted to quantitatively specify formulas for their model variables. Given the lack of any real formula specifications for their model, none of the groups would have been able to get beyond a basic model sketch and perform any higher order modeling activities such as testing and revising their models.

Sequential groups

Group 2, 3, and 6, took more of a sequential approach to the learning task; they started first in the lab and worked there primarily uninterrupted as theory room visits (or modeling activities), weren't long enough for productive work. The structure of the lab work for these groups is similar to those of the explorative groups. An example of this is found in Excerpt 3, Group 2's chat log.

Excerpt 3

1	Judith	You have to let the tank empty and fill so that the water level stays precisely the same.
2	Lonneke	Yes that's correct
3	Frank	Almost
4	Judith	So you have to simply make the flows the same size or not?
5	Lonneke	I do not understand this
6	Lonneke	Flow from the tap, that's what you should change

Most sequential groups ended their sessions with model work in the theory room with only sporadic and short periods in the lab. This did not prove productive given the state of Group 2, 3, and 6's models. Group 6 had no model work in evidence upon completion of the experiment. This may be due to the fact that Group 6 did not achieve equilibrium in the lab.

Chat data from Groups 2 and 3 revealed that they did achieve equilibrium in the lab before proceeding to the theory room to build their models. However, Group 2's log shows no evidence of any modeling activities in their log records, nor do they refer to any in their chat log. Instead their chat log within the theory room reveals mostly off-task communication and some regulatory discussions which indicate comprehension failures. Group 3's logs show evidence of attempted modeling, but they did not specify any variables and only attempted to specify one formula. All other variables were left unspecified and without any names. They did not attempt any runs of their model before their session was over.

5.4 Regulative tool use

According to Co-Lab's design philosophy, a substantial part of the regulation should take place in the meeting room using the PC. As the visits to the meeting room were infrequent, log file use of the PC revealed only a fraction of the groups' actual regulatory behavior with the tool. Data shown in Table 3-4 reveals that of the six groups that visited the meeting room, Groups 3, 6, and 8 *inspected* the PC. That is, they only attempted to open and close the PC, but did not try to go beyond opening and closing. Groups 2 and 4 also *explored* features in the PC such as the history, links, hint or report tabs, but they did not attempt to make any changes to its content such as creating sub-goals, or taking a note. Group 10 was the only group that tried to actually *use* the PC as a planning tool. They attempted to change variables within the PC, such as adding a goal, sub-goal or note. This group attempted to make these changes a total of 14 times. Their attempts were unsuccessful however, and their chat discussions indicate this was due to technical imperfections within the PC, which incidentally affected all group's use of the regulatory tool.Together, these findings indicate that the bulk of regulatory evidence for this study would be scored entirely from the chat discussions.

Table 3-4. Use of the Process Coordinator tool (PC)

	Non-Use	Inspect	Explore	Use
Group	1	3,6,8	2,4	10
PC use				
Frequency (min.)	0	3	1	7
Frequency (max.)	0	4	5	7
Time (min.)[a]	0	1	2	28
Time (max.)	0	2	146	166

[a] Time in seconds.

5.5. Regulative communication

In all, the groups wrote 2574 chat messages containing 2605 utterances. As shown in Table 3-5, approximately 25% of the utterances were off-task. Although online groups often begin their sessions social talking –for instance to introduce each other or to wait until all group members are present–, this was not the case here. Most groups were anxious to start the learning task, and some did not even have the courtesy to wait for all group members to login. Group 10 was an exception: two girls were social talking while waiting for the third group member who had difficulties logging in to the environment.

Groups 1 and 2 had the highest proportions of off-task utterances. Off-task discussions increased toward the end of the session. In Group 1 for instance, one student kept working on the learning task, and occasionally reported back to his group mates, who were engaged in off-task communication. In Group 2, off-task communication was relatively high throughout the entire session, but here the intensity increased towards the end of the session as well.

Table 3-5. Table 3 Classification of utterances

	Cognitive	Regulatory	Affective	Procedural	Off task
Group 1	11.07	32.55	3.36	18.12	34.90
Group 2	9.81	36.11	1.85	10.37	41.85
Group 3	11.46	40.83	8.54	15.00	24.17
Group 4	25.71	44.00	5.14	13.71	11.43
Group 6	17.54	44.03	5.97	10.07	22.39
Group 8	13.93	38.31	4.73	30.60	12.44
Group 10	21.49	33.03	6.33	18.55	20.59
Average	15.86	38.41	5.13	16.63	23.97

Note: Values indicate percentage.

Another striking result is the consistently high proportion of regulatory utterances, ranging from 32% to 44%. To get a better understanding of the content of the regulatory talk, regulatory utterances were grouped into episodes (see Table 3-6). The regulatory episodes were divided into two broad categories: collaboration and learning task, containing 133 and 47 episodes respectively.

Table 3-6. Occurrence rates of regulative episodes

Group	1	2	3	4	6	8	10	Total
Regulation of Collaboration (RC)								
Greeting	1	9	3	3	1	2	5	24
Attention	1	3	4	0	2	1	2	13
Task division	2	2	3	3	3	3	1	17
Room change	4	9	5	0	3	7	3	31
Control	2	6	8	1	1	1	6	25
Group Synch	3	1	7	6	5	1	0	23
Total	13	30	30	13	16	15	17	133
%RC	76.47	71.43	83.33	72.22	83.33	75.00	58.62	73.89
Regulation of the Learning Task (RLT)								
Planning	4	11	6	5	2	4	8	40
Monitoring	0	1	0	0	1	1	4	7
Total	4	12	6	5	3	5	12	47
% RLT	23.53	28.57	16.67	27.78	16.67	25.00	41.38	26.1

Regulation of collaboration

Regulation of collaboration serves to establish and maintain a common focus among group members. Table 3-6 presents an overview of the episodes of regulation of collaboration. An important aspect of regulation in synchronous online collaboration is to know and keep track of the whereabouts of the other group members. Students engaged in a high amount of greetings which signal a student's presence when first logged into Co-Lab, or in subsequent room changes. Discussing room changes is another instance of regulation of collaboration. Excerpt 4 nicely illustrates a collaborative decision to visit the meeting room. It also shows a typical greeting episode in lines 6-8.

Excerpt 4

1	Jane	should we go to meeting, theory or lab
2	Mary	let's meet :D
3	Odette	hahahaha YEAH(H)
4	Mary	because that's where the goals are, right?
The group moves to the meeting room		
6	Mary	welcome to my meeting room
7	Jane	haha
8	Odette	hello

Not every room change was explicitly agreed upon by the groups, however. Group 4, for instance, moved across rooms quite often (see Figure 3-3), but their chat files contained no room change episodes. In general, about 35% of the room changes were discussed in a regulatory episode. The remaining 65% comprised instances of one student merely announcing that he or she went to a different room, without making this decision the subject of group discussion. On other occasions, a student simply headed off to a different room without notice; his group members could tell his new location from the control tool, as illustrated in Excerpt 5.

Excerpt 5

1	Carl	Rob, why are you somewhere else?
2	Carl	come to the lab
3	Jack	what's Rob doing ?
4	Jack	what's he doing there !
5	Jack	in the theory
6	Rob	yeah yeah I'm in
7	Carl	OK then stay in
8	Carl	so we can help Jack

Such wanderings further illustrate a lack of agreement on task division. Despite the fact that most groups worked quite collaboratively, students occasionally agreed on a division of tasks, as is shown in Excerpt 6.

Excerpt 6

1	Frank	Yes, 1 is in control
2	Frank	You should think along
3	Frank	and type it in here
4	Odette	gosh...duh...
5	Frank	and I will enter it all
6	Romy	okay

Control changes were another topic of conversation. Although the control tool allowed students to request control by clicking the corresponding button, control changes were frequently discussed before they were put into practice. During the initial phases this may have been due to the fact that the operation of the control tool was unclear. During later stages, some groups kept deliberating over who should get control. On many occasions, the student who claimed to understand the task best was awarded control (see Excerpt 7).

Excerpt 7

1	Frank	I want control
2	Frank	I can do better than Romy ☺
3	Romy	how do I pass it on ?
4	Romy	yeah, right
5	Judith	okee!! Romy give it to Frank

Two types of episodes were observed to regain a common focus. One type illustrates attention seeking that is, students confront a student who has not contributed to the discussion for some time, or has wandered off to a different room without notifying his or her group members. Excerpt 7 shows this in lines 1 and 2 but as Figure 3-3 illustrates this type of episode was relatively scarce. The second type pertains to group synchronization. Group synchronization occurred when one student was working on his own for some time, and spontaneously reports back to his fellow students. Such catch up planning also occurred when one of the other students asked for clarification as shown in the last three lines of Excerpt 8.

Excerpt 8

1	Marco	What are you doing?
2	Bart	trying to make a model
3	Bart	but I do not understand much of it
4	Joyce	shouldn't we save that thing first
5	Bart	yeah, do it
Joyce goes to the lab to save their graph		
6	Bart	have you saved it Joice?
7	Joyce	no I couldn't
8	Bart	I'll try

Regulation of the learning task

Table 3-6 presents the regulation of the learning task episodes by group. Forty episodes were coded as planning; seven episodes were considered an instance of monitoring. Despite the relatively high amount of planning episodes, the groups hardly engaged in meaningful "goal setting type" activities. One reason is that 17 of the 40 planning episodes expressed students ignorance of the general approach to the learning task; as illustrated in Excerpt 9.

Excerpt 9

1	Romy	what should we do?
2	Frank	do not know
3	Judith	?

Another reason is a lack of systematic planning. Except for Group 10, the groups did not go to the meeting room to establish an overall approach to the learning task by formulating goals using the PC tool. Nor did they discuss overall task planning through the chat. Instead, students adopted a more ad-hoc planning. Such short-term planning episodes generally comprised a proposal for immediate action by one student and confirmations by the others. Excerpt 10 shows a typical example.

Excerpt 10

1	Kate	I think we should just use the simulation to compute how hard the tap should run.
3	Becky	sure
4	Kate	ok??
5	Kate	everybody agree?
6	Lisa	yes
7	Lisa	that's fine

As illustrated in Excerpt 11, Group 10 was the only group that actually elaborated on ad-hoc planning proposals. Such committed dialogues were absent in the other groups' discussions.

Excerpt 11

1	Kate	make a table or something
2	Lisa	ok, just make a table !
3	Becky	we have to make a model first
4	Becky	right?
5	Kate	oh
6	Lisa	but we have a model already
7	Lisa	what do you think I have been doing !
8	Becky	no I mean with those squares etc.
9	Kate	she means with the shapes I think
10	Lisa	do your best

Ad-hoc planning allows for students to monitor their own activities, regardless of how low-level these may be. Yet virtually no evidence of such monitoring was found in the chat files. Excerpt 11 shows a rare instance in lines 6 and 7 where Lisa reminds her group members that some modeling activities have already been accomplished.

While the lack of overall planning may have decreased the opportunities for monitoring, most ad-hoc plans implied goals that could (or should) be monitored. Such monitoring occurred sporadically, however, although Group 10 showed how it could be done in lines 4 and 5 of Excerpt 12.

Excerpt 12

1	Lisa	what should I change then?
2	Lisa	gimme some hints!!!
3	Kate	shouldn't we make a graph or something
4	Lisa	first make sure it doesn't overflow
5	Lisa	that was the point

Monitoring can also pertain to the students' understanding of the learning task. Five of the seven monitoring episodes were instances of such comprehension monitoring. Similar to the episode exemplified in Excerpt 9 these episodes merely expressed the students' ignorance rather than their understanding of the subject matter.

6. Discussion

The aim of this study was to identify and describe group activities within the initial stages of a Co-Lab session and to glean meaningful information regarding how to support students to collaboratively plan and monitor their inquiry learning. This discussion focuses first on the results of the navigational issues to contextualize how students approach the learning task. Secondly results of the student's regulative behavior with regard to their collaboration and the learning task are discussed to inform design decisions. Finally future research with regard to regulative support in Co-Lab is described.

The navigational issues discussed reveal that in the initial phases of a Co-Lab session groups spend a majority of their time on lab experimentation and to a lesser degree in modeling activities. The emphasis on work in the lab room may imply that students first attempt to gain an understanding of the simulation properties via experimentation prior to being able to translate what they find into a workable model; often before they have a full understanding of the task. None of the groups were able to attain a runnable model within their sessions, although many produced model fragments (model sketches which show variable types and relationships). Groups that took a more exploratory approach to the task evidenced more modeling activities than did the sequential groups. The description of the lab work within the approach to the learning task section also points to the fact that initial experimentation in the absence of any further support to the contrary shows students lack of a systematic approach. Their experimentation could be characterized as one in which learners attempt to create a desirable outcome, a so-called "engineering approach", instead of trying to understand the model (Schauble, Klopfer, & Raghavan, 1991).

Several tentative conclusions can be drawn from these results. The first is that students need more time within Co-Lab to move beyond orientation and into more systematic experimentation and deeper model building. Within one to two hours all the groups had done some orienting type experiments in the lab and tried (with some exceptions) some initial model sketching. But they did not move into a more systematic and meaningful application of the transformative inquiry learning processes. This may indicate that students need approximately one to two hours of this sort of orientation. As such, time on task expectations or task complexity should be reduced. The evidence from this study suggests further that groups who took an explorative approach achieved more model progress. Scaffolds which promote orienting with experimentation and model sketching iteratively could assist students both with model progress and possibly with more systematic work over time. All of these activities can be integrated within a regulative tool which encourages their application. Support for activities such as systematic experimentation, hypothesis generation and model refining may only be useful however

after students have engaged in sufficient exploration on their own of the environment.

As shown in the analysis of students' regulatory activities, they mainly engaged in regulation of the groups' collaboration. This may be typical of students working together for the first time, thus it may be expected that over time this type of regulation may decrease. This may also add to the emphasis put on orientation within a learning environment, as discussed in the previous section. Students need time to get oriented in working online and using the collaborative tools of Co-Lab. A factor which may have contributed to the high degree of regulation of collaboration may also be the fact that students engaged in little to no systematic planning of how they would approach the learning task.

Azevedo and Cromley, (2004) summarized the conditions under which good self-regulation takes place. Students need to be able to: (1) set meaningful goals from the learning situation, (2) determine the strategies for effective goal achievement, and (3) monitor their emerging understanding of the topic in order to make adjustments as needed for task progress related to contextual conditions. As the analysis on regulation of the learning task shows, none of the groups engaged in anything more than ad-hoc planning and their monitoring activities consisted mainly of expressions of comprehension failure. The collaborative regulation they conducted provides support for these outcomes in that very little group agreement was made with regard to task approach, rather group members wandered off, or control was given to the more capable student.

This result is not surprising given the lack of explicit support which students often require for self-regulation. Student learning with inquiry learning environments shows that students do not engage in planning and monitoring effectively and that specific support is required to assist students in effective self-regulation (Azevedo et al., 2005; Azevedo et al., 2004; De Jong & Van Joolingen, 1998; Greene & Land, 2000; Hannafin & Land, 1997; Schauble, Raghaven, & Glaser, 1993; White & Frederiksen, 1998). The relatively low instances of planning and monitoring found in the analysis combined with the technical difficulties which prevented the students from utilizing the tool designed for such support may indicate that students will not spontaneously make a plan and engage in monitoring without specified support. Future studies need to examine the effectiveness of the PC as a means of supporting students in planning and monitoring their inquiries.

Another factor which may have influenced students' lack of planning and monitoring is the fact that they needed to go to another room to do this, i.e., the meeting room. As seen in the analysis the students hardly visited the meeting room. A future design consideration may be to include the PC in each room as a means of providing consistent support and to keep

students focused. Further support for this can be found from looking at the collaboration of the students, it appears they groups will often divide tasks especially towards the end of the activity. This means that students need access to a regulative tool which can be used independently or collaboratively as they see fit.

Future research with Co-Lab needs to examine the effect which the PC tool has on assisting students in understanding the task but also in more systematic efforts for modeling and experimentation. Encouragement of taking an iterative approach to the task, and to plan and monitor their efforts also needs to be integrated within the PC. In the next study the effects of a fully specified PC containing both top level goals and sub-goals as well as specific hints and directions on student regulatory activities is examined.

4. Examining regulative scaffolds during inquiry learning[6]

Abstract

This study examined whether online tool support for regulation promotes student learning during inquiry learning with Co-Lab, a technology-enhanced learning environment. Sixty-one students worked in small groups to conduct a scientific inquiry with fluid dynamics. Groups in the experimental condition worked with the Process Coordinator (PC) a regulative support tool which contained guidelines for planning, monitoring and evaluation; control groups were given a version of this tool from which these instructions were removed. Results showed facilitative effects for the fully-specified support tool on learning outcomes and initial planning. Qualitative data elucidated how the regulative support enhanced learning and suggests ways to further improve regulative processes within inquiry learning settings.

[6] This chapter was adapted from Manlove, S., Lazonder, A.W., & De Jong, T. (2006). Regulative support for collaborative scientific inquiry learning. *Journal of Computer Assisted Learning, 22*, 87-98

"Nell had a pretty good idea of what to do with the chain. Starting with the end, she examined the toggles and began to mark their positions down (The Primer always gave her scratch pages when she needed them" (Stephenson, 1995, p. 314).

1. Introduction

The National Research Council advocates methods of science education that enable students to construct scientific understanding through an iterative process of theory building, criticism, and refinement based on their own questions, hypotheses, and data analysis activities (Bransford et al., 2000). These notions of learning science coincide with the tenets of inquiry learning. This didactical approach describes science learning as students working in groups to perform experiments and build computer models to induce, express, and refine scientific knowledge. Recent technological advances have enhanced the possibilities to mediate these learning processes with electronic environments, tools, and resources. Learning within these environments is generally assumed to lead to a deeper and more meaningful understanding because students process scientific content in an active, constructive, and authentic way.

However, a review by De Jong and Van Joolingen (1998) showed that the effectiveness of inquiry learning is challenged by intrinsic problems many students have with this mode of learning. For example, students often have difficulty formulating testable hypotheses, designing conclusive experiments and attending to compatible data. Within modeling, students often fail to engage in dynamic iterations between examining output and revising models (Hogan & Thomas, 2001). These problems are usually addressed by cognitive tools: support structures which aim to compensate for students' knowledge or skill deficiencies. Examples of effective support tools include proposition tables to help generate hypotheses (De Jong, 2006b), adaptive advice for extrapolating knowledge from simulations (Leutner, 1993), and model progression to assist students in dealing with the complexity of simulations (Swaak et al., 1998). Recent overviews of cognitive tools for inquiry learning are given by (De Jong, 2006b; Linn, Bell, & Davis, 2004; Quintana et al., 2004)

Another class of problems pertains to the students' ability to regulate their own learning. Inquiry learning typically requires high degrees of cognitive regulation in that students have to *plan* a series of experiments, *monitor* progress and comprehension, and *evaluate* their inquiry learning processes and knowledge gains. The student-centered designs utilized in inquiry learning environments tacitly assume that students are proficient self-regulators. Research has shown that poor self-regulatory skills often get in the way of students' learning within these environments (De Jong & Van Joolingen, 1998; Land, 2000). To elucidate these skill deficiencies, the study depicted in chapter 3 examined students' unprompted

regulative behavior during inquiry learning. Students worked online in seven triads on an inquiry learning task, receiving no regulative support. Results showed that, although students frequently regulated their within-group collaboration, they performed very little spontaneous or serious planning and monitoring of the learning task.

These findings signal a need to assist students in regulating their scientific inquiries. Early attempts to scaffold students' regulative skills with detached or separate instruction has proved generally ineffective or provided mixed results (Roth & Roychoudhury, 1993). Subsequent attempts have therefore tried to embed regulative support within the inquiry learning process. A typical example is the Inquiry Cycle, a planning framework used within the Thinker Tools curriculum to scaffold students' inquiry and modeling activities (White, Shimoda, & Frederiksen, 1999). A comparable approach was used by Njoo and De Jong (1993) who offered students a stepwise description of the inquiry learning process and paper worksheets to record the results obtained during each step. Veenman, Elshout and Busato, (1994) utilized system-generated prompts to direct students' attention to the regulatory aspects of their inquiry task. Zhang, Chen, Sun, and Reid, (2004) supported regulation of students' inquiry through process displays and prompts designed to promote reflection. In all of these studies, students who had access to regulative support during task performance surpassed students who received no such support.

Inquiry learning environments have taken regulative support to the next level by fully integrating regulative scaffolds within the environment. Such online tool support typically combines regulative hints and explanations with electronic facilities for students to record, monitor, and evaluate their own plans, hypotheses, experimental data and models. For example, the Progress Portfolio used within the Create-a-World Project curriculum allows students to record, annotate, and organize intermediate project results. By documenting the students' products through the course of their inquiry, the Portfolio provides students with concrete products for monitoring and reflection (Edelson, 2001). The WISE environment (Slotta, 2004) gives students an overview of the inquiry task and scaffolds their regulative skills with planning and monitoring tools. In BGuILE, an environment for guided inquiry learning in biology, progression activities are utilized to incrementally prepare students for the more open-ended nature of an inquiry. Support tools like the ExplanationConstructor and a data log further assist students in organizing experimental data, offer domain-specific explanation guides, and encourage monitoring and reflection while students are conducting their inquiries (Reiser et al., 2001).

Although at face value the potential of these tools is quite compelling, there have been very few systematic evaluations of their effectiveness. The current research therefore attempts to offer empirical evidence regarding

the potentials of online tool support for regulation during inquiry learning. Prior to explicating the design of the study, a brief overview of a framework of self-regulation is given in order to contextualize the design rationale and the features of the online support tool.

2. Self-regulation framework

Models of self-regulation define the metacognitive processes and strategies expert learners use to improve learning (Butler & Winne, 1995; Schraw & Moshman, 1995; Zimmerman, 2001). While many self-regulation models include a behavioral and motivational aspect (cf.,Kuhl, 2000) the research presented here focuses on what Pintrich (2000) calls *cognitive* regulation. That is, how students engage in a recursive process which utilizes feedback mechanisms to direct and adjust their learning and problem solving activities (Azevedo et al., 2004). Most cognitive regulation models distinguish three phases within the cyclical process of self-regulation, namely planning, monitoring, and evaluating. As these phases resemble the regulative activities students should engage in during inquiry learning (Njoo & De Jong, 1993), valuable insights for the design of regulative inquiry learning support might be gleaned from models of self-regulation.

In the planning phase students engage in problem orientation, goal setting and strategic planning. Problem orientation entails analyzing both the task and the resources available to perform the task. Students utilize this task understanding to set goals for their learning. Highly self-regulated learners organize their goals hierarchically, such that process goals operate as proximal regulators of more distal outcome goals (Zimmerman, 2000). Thus it is expected that students would benefit from a hierarchical structure of goals when trying to foster self-regulation. Assisting students in setting more specific sub-goals helps them develop strategic plans. These plans convey the students' ideas for how to approach superordinate goals through subordinate sub-goals, as well as implicit standards used for regulation of their collaboration and learning objects. In inquiry learning, planning is often supported by a top-level model of the inquiry process. This model is made explicit to students and is presented as a sequence of goals and sub-goals to be pursued (White et al., 1999). In addition to providing students with a model, placing students in a collaborative setting may assist them in more precise goal setting

Throughout the execution of a strategic plan, students monitor what they are doing to ensure that they are making progress toward the specified goals (Ertmer & Newby, 1996). Thus the sub-goals that constitute a strategic plan are also the measure by which students monitor comprehension and task performance (Schraw, 1998; Winne, 1997).

Monitoring can occur at any moment during task execution, depending in part on the students' actions and the results thereof (Salovaara & Järvelä, 2003). As the nature of these cues is difficult to anticipate, monitoring can be supported by generic prompts that encourage students to mentally check and adjust performance. Directions to take notes is a good example. Note taking involves a momentary interruption of task performance to externalize thoughts about the task in writing. It promotes the active generation of relations between student's inquiry learning products and their prior knowledge (Kiewra et al., 1991). Allowing students to append notes to sub-goals assists them in efficient organization of their thoughts, and provides standards against which comprehension and learning progress can be judged. In collaborative settings, note taking is assumed to trigger discussions on intermediate results and the processes through which these results were obtained. These discussions in turn can cause group members to monitor their own task understanding. Within inquiry learning environments, students then need access to an online regulatory tool which supports appended note taking, as well as directions for taking notes and discussing them.

During the evaluation phase, students assess both the processes employed and the products achieved (De Jong, 2006b; Ertmer & Newby, 1996). Evaluation of learning processes involves any reflection on the quality of their planning, how well they executed their plan and how well they collaborated. Evaluation of learning products involves student assessment of learning objects and outcomes they have created. Generally students evaluate by comparing how well their performance and learning fits with the goals and standards they have set during planning. As with monitoring, expressing thoughts in writing might assist students in evaluating their work. In inquiry learning, students are often asked to write a research report (White et al., 1999). To guide them in writing their reports, students could be given a report template which augments the inquiry process model by unpacking the goals and sub-goals associated with each step.

Together these phases capture what highly-self-regulated learners do. However, when high-school students engage in inquiry learning, they perform very few of the activities discussed in this framework (Manlove & Lazonder, 2004, see chapter 3). This result indicates the need to support students in planning, monitoring and evaluating their inquiries. Towards this end, implications for designing regulative scaffolds and support were drawn from the processes described above. These implications indicate that students should be promoted and directed to (1) set goals that reflect the phases of scientific inquiry, (2) form a strategic plan by setting sub-goals, (3) highlight strategies to achieve these sub-goals, (4) monitor progress by taking notes and appending these to goals and sub-goals, and (5) evaluate both their inquiry learning processes and their models utilizing a report template and standards implicit in goal hierarchies.

The study reported below sought to determine if online tool support designed according to these implications promotes students' regulatory activities and learning. The study employed a randomized group design with two conditions. Groups in both conditions utilized the Process Coordinator (hereafter PC) to regulate their inquiry. In the experimental condition (PC+), regulative directions were embedded within the tool. In keeping with the design implications, this PC included a hierarchy of goals and sub-goals, hints and explanations, and a template for the final report. Students in the control condition (PC–) were given a similar version of this tool, however, it contained no regulative directions. PC+ groups were expected to achieve higher learning outcomes and produce more instances of planning, monitoring, and evaluating than PC– groups.

In this study collaboration was chosen as a context for inquiry learning. Collaboration in inquiry leads to improved inquiry processes and better results (cf., Okada & Simon, 1997) and relates positively to self-regulation. Research has shown that students who work together show both higher instances and increased awareness of self-regulation over students who work individually (Lazonder, 2005; Manion & Alexander, 1997). In order to allow for a fair comparison, collaboration was used in both conditions.

3. Method

3.1. Participants

Sixty-one high-school students (aged 16-18) worked in 19 triads and 2 dyads formed by track ability matching. Subsequent random allocation of student groups to conditions resulted in 10 PC+ groups and 11 PC– groups. Due to technical difficulties in the learning environment and absentee students, incomplete data were retrieved for 3 PC+ groups and 2 PC– groups. Missing data were excluded on an analysis-by-analysis basis.

3.2. Materials

Groups in both conditions worked on an inquiry task within fluid dynamics that invited them to discover which factors influence the time to empty a water tank. This task was performed within Co-Lab, a collaborative discovery learning environment in which the groups could experiment through a computer simulation of a water tank, and express acquired understanding in a group developed, runnable, system dynamics model. Group members could discuss their inquiry with a synchronized chat (see chapter 2 for a description of Co-Lab). By judging model output against the simulation's results, students could adjust or fine-tune their model and thus build an increasingly elaborate understanding of fluid dynamics.

Regulation of the inquiry learning process was supported by the PC. Groups in the PC– condition could use the tool to set, monitor and evaluate their own goals. In the PC– condition there were *no* preset sub-goals, descriptions, hints, or report templates. Students in the PC+ condition however, received a version of this tool that contained a set of goals and sub-goals that outlined the phases students should go through in performing their inquiry (see Figure 4-1). Each sub-goal came with an explanation students could view by clicking the "Description" tab. For each sub-goal there were one or more hints that proposed strategies for goal attainment. Hints directed students to plan for writing down intermediate results at key moments during their inquiry. Note taking required students to click the "Notes" tab to open up an entry field where they could type text. Notes were automatically attached to the active sub-goal and could be inspected by clicking the "History" tab. As the center image of Figure 4-1 shows, this action changed the outlook of the PC such that it revealed the goals and the notes students attached to them in chronological order. Clicking the "Generate report" tab again changed the outlook. Students now saw the goal tree, the History window and a report template that could be filled in by typing text and copying notes from the History window. Sub-goals pointed students at the appropriate moments to start their evaluations; hints were used to offer directions on the ways and criteria to evaluate the quality of the students' model and learning process. The remaining features were similar across conditions.

3.3. Procedure

The experiment was conducted over three weekly one-hour lessons that were run in the school's computer lab. The first lesson involved a guided tour of Co-Lab and an introduction to modeling. During the guided tour students in both conditions were taught to plan, monitor, and evaluate their learning with the version of the PC tool they would receive. The modeling tutorial familiarized students with system dynamics modeling

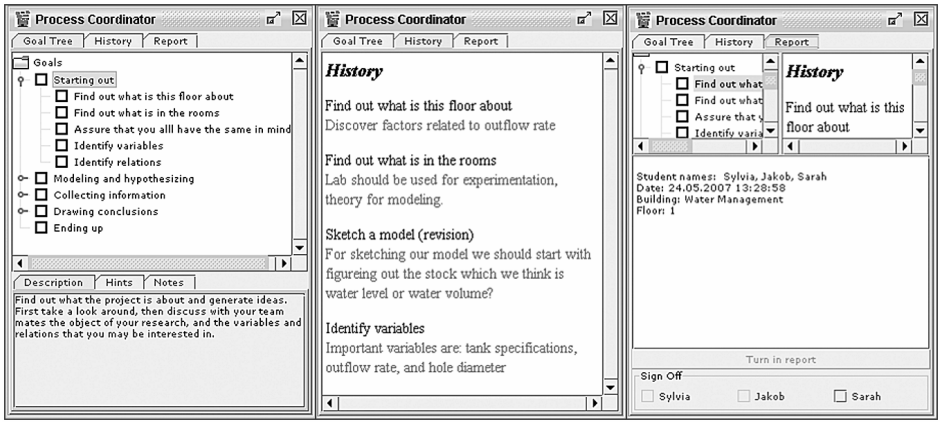


Figure 4-1. Goal tree view (left), History view (middle) and Report view (right) of the PC+.

language and the operation of Co-Lab's modeling tool. It contextualized the modeling process within a common situation, the inflow and outflow of money from a bank account. Students completed the individual modeling introduction within twenty minutes. In the next two lessons (hereafter: session 1 and session 2) students worked on the inquiry task. They were seated in the computer lab with group members dispersed throughout the room in order to prevent face-to-face communication. Students were directed to begin by reading the assignment, to use the PC tool for planning and to use only the chat for communication. The students were then left to conduct their inquiries. Assistance was given on technical issues only.

3.4. Coding and scoring

Models convey students' conceptual domain knowledge from variable and relationship specification, and demonstrate scientific reasoning through overall model structure (White et al., 1999). Learning outcomes were therefore assessed from the number of correctly specified variables and relations in the models created by the groups of students. In all cases, "correct" was judged from the reference model shown in Figure 4-2. One point was awarded for each correctly named variable; an additional point was given if that variable was of the correct type. Concerning relations, one point was awarded for each correct link between two variables. Up to two additional points could be earned if the direction and type of the relation was correct. The maximum model quality score was 26. Inter-rater reliability estimates for constituent parts of the model quality score were high, with Kappa values ranging from 0.90 to 1.00.

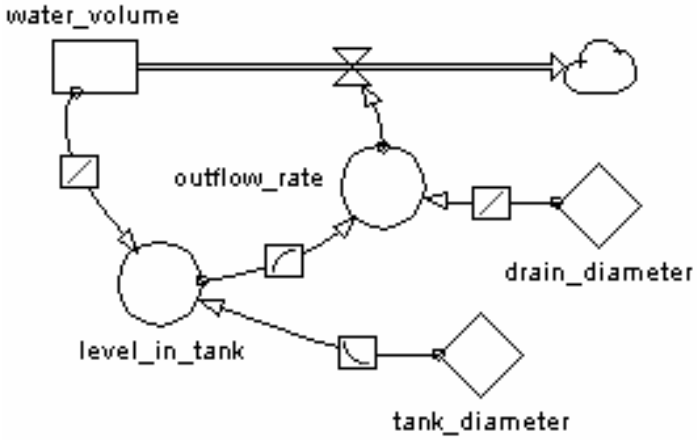


Figure 4-2. Reference model for the experimental task.

Students' use of the PC tool was scored from the log files. PC actions associated with planning were (1) viewing of specific goals, (2) adding goals or sub-goals, (3) viewing hints, and (4) viewing the goal descriptions. Monitoring was defined by three actions: (1) adding notes to goals, (2) marking goals complete, and (3) checking the history. Evaluation was assessed from (1) generating the report by clicking the corresponding tab, and (2) writing within the report.

Verbal interaction was scored from the chat history files using an iterative approach. First the basic unit of analysis was determined by segmenting chat messages into utterances. An utterance was defined as a collection of words with a single communicative function. Each utterance was then classified according to its function in the dialogue. Here a distinction was made between cognitive, regulative, affective, procedural, and off-task utterances. Cognitive utterances were defined as statements which relate to the learning task. A regulative utterance dealt with any planning, monitoring or evaluation of the learning task. Affective utterances were coded when students made their feelings about the task or learning environment known. Procedural utterances pertained to statements about the operation of the tools within Co-Lab or the navigation of the environment. Off-task utterances were coded when students talked about anything other than the learning task, environment, or tools.

Beyond the utterance coding, same-type, conceptually related utterances were grouped into episodes. Category labels were thus passed down from utterances to episodes. Regulative episodes were further classified as regulation of collaboration (RC) and regulation of the learning task (RLT). RC episodes pertained to any discussion of group work and included greetings (i.e., signing on and signing off; see line 1 in Excerpt 1), task divisions, and expressions asking what group members are doing or where they are in the environment. Excerpt 1 depicts an RC episode in which two group members negotiate task division and collaboration.

Excerpt 1

1	Bobby	I'm going to the lab to do experiments.
2	Sherry	Okay, I had started already, but I do not understand it very well.
3	Bobby	Can I try?
4	Sherry	Yes, of course.
5	Bobby	Click on 'release control' then
6	Bobby	The yellow button.

RLT episodes entailed conversations regarding planning or approaching the learning task, monitoring their progress, learning outcomes, or comprehension as well as evaluative conversations regarding learning activities and learning outcomes. The RLT episode in Excerpt 2 shows the same group checking their understanding and use of simulation values in their modeling work.

Excerpt 2

1	Sherry	Hmmmzz, I think I made a mistake.
2	Sherry	What I sent you was an example.
3	Bobby	I'm making a model, do not touch it.
4	Sherry	No I won't, but in the lab, tank level has other values.
5	Bobby	We can also put other values in, no problem, but we'll do that later.
6	Sherry	I just looked when I came in [the lab], and didn't click anything.
7	Sherry	Okay

Two raters used this rubric in coding the chat files of two groups. Inter-rater agreement for segmentation reached 90% for the utterances and 68% for episodes; agreement estimates (Cohen's Kappa) for the classification of utterances and episodes were .65 and .95 respectively.

3.5. Data analysis

Data analysis focused on between-group differences in learning outcomes and learning activities (i.e., PC use and verbal interaction). Given the relatively small sample size and the skewness of some distributions, between-group differences were analyzed by non-parametric Mann-Whitney U tests. Correlations were computed between learning activities and learning outcomes. Subsequent qualitative analyses were conducted to shed light on the nature of the students' discussions and resolve issues that remained unclear from the quantitative analyses.

4. Results

4.1. Learning outcomes

Learning outcomes were indicated by the quality of the groups' final model solutions. As most groups were unable to attain complete models, the average model quality scores displayed in Table 4-1 were somewhat low. They nevertheless seem to differentiate between groups as shown by the considerable range in scores. Mann-Whitney U tests further demonstrated that PC+ groups on average achieved significantly higher model quality scores than PC– groups.

Table 4-1. Mean scores (and standard deviations) for learning outcomes and learning activities

	PC+ (*n*=7)	PC– (*n*=9)	*Z*
Model quality	9.38 (4.03)	5.78 (3.77)	–2.07*
Frequency of PC use			
Planning	96.88 (31.82)	21.89 (9.49)	–3.37**
Monitoring	18.11 (15.96)	17.00 (15.13)	–0.04
Evaluating	0.00 (0.00)	0.22 (0.44)	–1.38
Proportion of episodes			
Affective	1.74 (1.98)	2.76 (1.61)	–0.80
Cognitive	12.65 (5.69)	7.03 (2.96)	–2.31*
Procedural	18.28 (5.42)	19.21 (5.58)	–0.32
RC [a]	33.72 (9.17)	39.35 (8.97)	–0.89
RLT [b]	33.61 (6.03)	31.64 (9.99)	–1.05

[a] Regulation of collaboration
[b] Regulation of the learning task
* $p<.05$ ** $p<.01$

4.2. Learning activities

Analyses of learning activities focused on the groups' use of the PC tool and their verbal interactions. As shown in Table 4-1, PC+ groups performed significantly more PC actions associated with planning than PC– groups did. Table 4-1 also shows a high standard deviation in the planning scores of the PC+ groups. Closer examination of the frequencies within the individual variables of the composite planning score indicated that one PC+ group viewed goals sparingly while another group excessively consulted goal descriptions. Monitoring actions were performed less frequently overall, and instructional condition had no effect on this measure. Apparently, students in the PC+ condition used the PC for monitoring purposes just as often as their PC– counterparts did. Following the same pattern, PC actions associated with evaluating were few and comparable across conditions. However, as none of the groups reached a point in their inquiry where it would have been appropriate to evaluate their work, evaluation activities were excluded from the remaining analyses.

Verbal interaction data were analyzed to examine whether groups in both conditions communicated differently about the task and its regulation. Across two sessions, 16 groups wrote 7274 chat messages containing 7456 utterances, which were merged into 887 episodes. From visual inspection of the means displayed in Table 4-1, it appears that students overall engaged in a higher percentage of regulatory discussions than any other

category. However, groups in both conditions produced comparable proportions of regulative episodes. Analyses for the other episode categories revealed that instructional condition had an effect on cognitive episodes, with PC+ groups showing a higher proportion of these episodes than PC– groups. The proportions of affective and procedural episodes were comparable across conditions.

4.3. Correlations

Correlational analyses were performed to reveal how model quality scores relate to learning activities. Table 4-2 shows that in both conditions model quality was not associated with PC use for planning and monitoring. In PC– groups, model quality correlated with the proportions of cognitive and RLT episodes. A significant negative correlation was found for RC episodes, indicating that groups who engaged in more regulation of their group work also had lower model quality scores. In the PC+ condition, model quality was not related to any of the episode categories. However, the substantial negative correlation (albeit not significant) between model quality and RLT episodes suggests that groups with lower instances of regulation of the learning task communication tended to achieve higher model quality scores. This result might imply that offering sub-goals, descriptions, and hints via the PC reduces the need for elaborate discussions on the meaning and planning of the task within this condition. This was borne out by the substantial negative correlation between proportion of RLT episodes and the number of times groups viewed goal descriptions ($r = -.89$, $p < .01$).

Table 4-2. Correlations between model quality and learning activities by condition

	Model quality	
	PC+ (n=8)	PC– (n=8)
Frequency of PC use		
Planning	-.18	-.24
Monitoring	-.03	-.34
Proportion of episodes		
Cognitive	.39	.64*
RC[a]	.00	-.66*
RLT[b]	-.59	.81**

[a] Regulation of collaboration
[b] Regulation of the learning task
* $p < .05$ (one-tailed) ** $p < .01$ (one-tailed)

4.4. Qualitative analyses of verbal interaction

Qualitative analyses confirmed the notion that the support offered by the PC+ reduced the need for regulative talk (RLT episodes). PC+ groups could simply follow the goals listed in the PC, and their chat files indicated that they initially did so. In session 1, all PC+ groups had at least one RLT episode in which students proposed to consult the PC in planning their inquiries. Excerpt 3 contains one of the best illustrations of how a PC+ group followed the goal tree within the PC.

Excerpt 3

1	Bryan	We need to go to the Process Coordinator
2	Bryan	Go there then
3	Bryan	To make a plan
…	…	…
4	Bryan	Should we first start with “Starting out”?
5	Bryan	Yes, the first two things we know, right??
6	Bryan	Right??
7	Bryan	Now to “Create a common understanding”
…	…	…
8	Bryan	Mitchell, how should I write the assignment in our own words?
9	Mitchell	First let’s look again at the assignment
10	Bryan	Then I’ll fill it in, save it…and so on.
11	Bryan	Okay?
…	…	…
12	Bryan	Okay the next one
13	Bryan	“Identify variables”
14	Mitchell	Amount of water
15	Mitchell	Opening
16	Bryan	Diameter opening
17	Mitchell	Yes great
18	Bryan	The question is “what are the central variables?”
19	Bryan	Mitchell can you put them in under “notes”?

Thus the PC+ gave groups a head start, clarifying the approach to the task and thereby making lengthy discussions on these issues unnecessary. However, once the PC+ groups had attained a global understanding of the task, they focused on task execution and hardly returned to the PC tool. Log file analysis showed that 6 PC+ groups did not use the PC during the final hour of the experiment; 2 groups performed the last PC-action 30 minutes prior to the end of the experiment. This in turn might account for the comparatively low scores for PC actions indicating monitoring.

Further qualitative analysis confirmed the notion that PC+ groups, in lieu of using the PC for monitoring purposes, relied on their own discussions to monitor their progress and task comprehension. RLT episodes in session 2 almost entirely contained task monitoring discussions. For example, every PC+ group had multiple RLT episodes that monitored specifically modeling work. The content of these discussions included

checking simulation values for specifying their models, the meaning of data sets, and checks of their progress on modeling work. In contrast, RLT episodes in session 1 consisted almost entirely of planning and orientation type discussions and almost no monitoring or checking of task specific understanding. These planning discussions usually contained expressions of not understanding, and attempts to begin to understand the task such as re-reading the assignment, reiterating the final goal, or checking the PC for a place to start.

Qualitative analysis also sought to reveal why the cognitive episodes did not correlate with model quality scores in the PC+ condition. Prompted by the PC goals, PC+ groups initially explored and discussed the settings and specifications of variables in the simulation. However, these discussions proved ineffective when the *relations* between these variables remained unaddressed. This was most apparent in Group 13. This group had a low model quality score and a relatively high degree of cognitive episodes. As illustrated in lines 1 – 11 of Excerpt 4, their cognitive talk focused almost exclusively on determining the settings of variables in their model. The overall model structure and relationships between variables was ignored until the very last minute of the experiment (lines 12 – 13).

Excerpt 4

1	Dustin	You have to begin with a full watertank
2	Mitchell	I do not know, but we have to have a formula for the inflow and outflow, because they can vary
3	Bryan	Yes they can change
4	Mitchell	But you selected a fixed unit
5	Bryan	Me?? It was an accident
6	Mitchell	Nope
7	Mitchell	You have to put .03 or so, something with a three
8	Mitchell	For unit
9	Bryan	That is for starting value, that makes sense to me, because that's the diameter for the drain pipe.
10	Bryan	But not by unit, that doesn't make sense.
11	Dustin	What should it be then?
…	…	…
12	Bryan	We also need to put in some sort of relationships!
13	Mitchell	Oh yeah

Group 7 also had a high amount of cognitive episodes but only an average model quality score. In following the directions from the PC, this group initially focused on the variables in the simulation. Their discussions also addressed relationships between pairs of variables (see Excerpt 5), but paid no attention to the overall model structure. The patchy knowledge that resulted from these discussions was used to model the influence of the drain diameter on water outflow rate. The group then started to fine-tune this relationship, while it would have been more efficient to complete the overall model structure by entering all variables that were deemed relevant in the model.

Excerpt 5

1	Karl	The relations
2	Felicity	The wider the drain pipe…the faster the water flows out
3	Karl	The wider the hole, the faster…..
4	Felicity	More volume…more pressure…water flows faster?
5	Karl	You know….concerning resistance…..that tank is just as full every time
6	Karl	So…I do not know, maybe water has the same power
7	Chris	I think pressure is irrelevant
8	Felicity	Yes, you're right
9	Karl	Thought so too
10	Felicity	Only the hole matters

Group 1 in contrast had relatively few cognitive episodes but a high model quality score. This is probably due to the fact that this group agreed on a division of tasks, with the most knowledgeable student in charge of modeling. Cognitive episodes mainly involved this student requesting information for the model from the other students. This is illustrated in Excerpt 6.

Excerpt 6

1	Ben	I need the water volume
2	Ben	So?
3	Sheryl	You can change it yourself
4	Sheryl	Level in the tank is 0.500
5	Sheryl	The diameter is now 0.44 meters
6	Sheryl	You can also change that
7	Sheryl	But now it is at 0.500 m
8	Sheryl	And diameter is 0.44m
9	Ben	Thanks

5. Discussion

In order to offset the complexities found during inquiry learning, instructional supports are necessary, particularly when it comes to helping students engage in regulatory actions. The hypothesis of this study was that providing regulative guidelines via online tool support would help students create better domain models and show increased instances of planning, monitoring, and evaluation activities.

Results for model quality and planning actions were consistent with expectations. PC+ groups had significantly higher model quality scores and used the PC for planning purposes more often than PC– groups did. The latter difference arose because PC+ groups consulted the PC frequently during the initial stages of their inquiry. Thus the regulative directions in the PC+ gave students a head start, reducing the need for

lengthy discussions to develop task understanding and strategic plans. This in turn created more opportunity to engage in cognitive discussion of the learning task, which was borne out by the significantly higher proportion of cognitive episodes in the PC+ condition.

However, a significant correlation between cognitive talk and model quality was found only within the PC– condition. Qualitative analysis revealed why. Three PC+ groups deviated from the pattern that a relationship exists between model quality and percent of cognitive episodes. It seems that one group relied solely on the expertise of one student within the group to generate a high quality model despite relatively few cognitive episodes. The other two groups seemed to follow the PC's directions to identify variables and their relations. As these groups abandoned the PC early on, they missed subsequent directions to establish an overall model structure, and maintained their focus on relationships between pairs of variables throughout their inquiry. A related study with Co-Lab showed that model structure as a whole is a key factor in successful model-based inquiry learning (Sins, Savelsbergh, & Van Joolingen, 2005). This result lends support for the need to encourage student engagement with model structure in intermediate phases of their inquiry learning.

Contrary to expectations, the regulative guidelines within the PC+ did not lead to higher instances of monitoring and evaluating. The latter result is probably may be due to a lack of time to complete the task. The comparable and low scores for monitoring might be explained from the fact that PC+ groups abandoned the PC after task understanding was reached. One reason for this abandonment may be that the PC+ groups relied more on their discussions to monitor than the PC tool, as was shown in the qualitative analysis of RLT episodes across sessions. However, this might also indicate that the PC tool separated monitoring from task execution in a manner that was not efficient for students. Embedding regulative support for monitoring via note-taking in a manner more consistent with task execution may be a more fruitful option.

Overall this study indicates positive effects for regulative guidelines during inquiry learning. Although the small sample size limits the study's scope and generalizability, its results demonstrate that students who had access to regulative instructions performed increased planning activities. Results were less conclusive for an increase in monitoring activities. Future research with larger samples should therefore investigate ways to further improve regulative support. One suggestion would be to examine whether system-generated prompts can promote PC use during intermediate and final stages of an inquiry. These prompts may come in the form of pop-up windows that remind students at intervals to monitor their progress. Alternately, feedback loops are the trigger for students to engage in monitoring, evaluation and adaptation of their learning processes (Butler & Winne, 1995). Research might also investigate where

feedback loops could be augmented as more "natural" prompts in the other tools within the environment in order to enhance the use of the PC. Log file analysis of the sort used in this study is particularly useful for this type of research as it allows researchers to correlate points of activity with students' discussions to glean information about what sort of feedback students are attending to when they monitor their work.

Still, caution is needed against relying solely on embedded support for regulative activities within inquiry learning environments (Land, 2000). Just because a regulative support tool exists does not mean that students will use it effectively. This indicates two potential problems for designing regulative support tools. The first is that support might *take the place of* regulative activities rather than *scaffold* them. Providing students with complete goal lists for example, may cause them to simply follow these directions rather than *think* about how to approach the task. Future research should address the fine line exemplified here between *scaffolding* and *replacing* regulative processes. The second is the problem of metacognitive awareness: students often are ignorant of their needs for assistance or are approaching a task inefficiently especially in light of the multiple, recursive activities involved in inquiry learning. Future research needs to address whether or not imposed use of a regulative support tool at key points within and across sessions might raise students' awareness of the difficulties they are having and how to correct them.

5. Refining regulative scaffolds during inquiry learning[7]

Abstract

This research addresses issues in the design of online scaffolds for regulation within inquiry learning environments. The learning environment in this study included a physics simulation, data analysis tools, and a model editor for students to create runnable models. A regulative support tool called the Process Coordinator (PC) was designed to assist students in planning, monitoring, and evaluating their investigative efforts within this environment. In an empirical evaluation, 20 dyads received a "full" version of the PC with regulative guidelines; dyads in the control group (n=15) worked with an "empty" PC which contained minimal structures for regulative support. Results showed that both the frequency and duration of regulative tool use differed in favor of the PC+ dyads, who also wrote better lab reports. PC–dyads viewed the content help files more often and produced better domain models. Implications of these differential effects are discussed and suggestions for future research are advanced.

[7] This chapter was adapted from Manlove, S., Lazonder, A.W., & De Jong, T. (in press), Software scaffolds to promote regulation during scientific inquiry learning. *Metacognition and Learning*.

"It would have been easy enough to conclude that this whole castle was, like the others, a Turing machine. But the Primer had taught Nell to be very careful about making unwarranted assumptions" (Stephenson, 1995, p. 314).

1. Introduction

This paper addresses issues in the design of online tool support within inquiry learning environments. These environments enable students to learn science by doing science, offering resources to develop sound scientific understanding by engaging in knowledge inference processes such as hypothesis generation, experimentation, and drawing conclusions (De Jong, 2006b; Swaak, Van Joolingen, & De Jong, 1998). However, knowledge gains through inquiry are also influenced by metacognitive factors such as the learners' knowledge and regulation of their own cognitions (Chin & Brown, 2000; Kuhn et al., 2000; Schoenfeld, 1992). Expert learners are thought to employ planning, monitoring, and evaluation processes while utilizing self-knowledge, task requirements, and a repertoire of strategies to achieve academic goals and objectives (Ertmer & Newby, 1996; Schraw, 1998). Research has demonstrated that students who actively regulate their cognitions through these processes show higher learning gains over students who do not (Azevedo et al., 2004).

Despite these benefits, students typically evidence very few instances of regulation during their inquiry work (De Jong & Van Joolingen, 1998; Land, 2000; Manlove & Lazonder, 2004). This is especially relevant for technology-enhanced inquiry learning where students are offered several software tools to infer domain knowledge, but require guidance for the regulative aspects of their inquiry. In order to compensate for low levels of regulation, researchers have turned to the development of regulative support tools. White and Frederiksen's (1998) Thinker Tools curriculum promoted regulative skills via scaffolds for planning, monitoring, and evaluation. Veenman, Elshout, and Busato (1994) utilized system-generated prompts to direct students' attention to the regulatory aspects of their inquiry task. Quintana et al., (2004), Kapa (2001), and Zhang, Chen, Sun, and Reid (2004) also espoused the value of promoting and supporting regulative skills such as process management, reflection, and meta-level functioning within inquiry learning environments.

Although at face value the potential of regulative tool support is quite compelling, there have been few systematic evaluations of their effectiveness. The current research therefore attempts to offer empirical evidence regarding the potentials of a software tool which supports inquiry learning through planning, monitoring, and evaluation. Prior to explicating the design of the study, a brief overview of a framework of self-regulation is given in order to contextualize the design rationale and the features of the support tool.

2. Self-regulation in inquiry learning

Self-regulated learning refers to a student's active and intentional generation of thoughts, feelings, and actions which are planned and adapted cyclically for goal attainment (Zimmerman, 2000). Regulation of cognition is an area of self-regulated learning (Pintrich, 2000) which focuses on the strategies students use to control and regulate their thinking during learning or task performance. Cognitive regulation is a recursive process which comprises three main phases: planning, monitoring, and evaluation. These phases are consistent with the regulative processes students should engage in during inquiry learning (Njoo & De Jong, 1993).

2.1. Planning

When highly self-regulating students are first introduced to a learning task, they begin to assimilate and coordinate conditions about the task. The result of this problem orientation process is the students' definition of what they are to do (Winne, 2001). Goals and sub-goals formed from this initial task understanding help students decide on specific outcomes of learning or performance (Zimmerman, 2000). Goals of highly self-regulated individuals according to Zimmerman "are organized hierarchically, such that process goals operate as proximal regulators of more distal outcome goals" (p. 17). In situations calling for scientific reasoning, the phases of scientific inquiry (orientation, hypothesis formation, experimentation, and drawing conclusions) become these process goals (White & Frederiksen, 1998). Key activities within each phase may be transformed into sub-goals. The resulting goal hierarchies, once established, become the strategic plans students use to perform an academic task (Winne, 2001), and the standards against which they monitor and evaluate their performance. As self-regulation is a recursive process, students will most likely abandon, adapt, or refine plans, task definitions, and standards as they progress through the task.

2.2. Monitoring

Once highly self-regulated students begin to execute their strategic plans, they begin to monitor their comprehension and task performance. Monitoring involves a comparison of students' current knowledge or the current state of a learning product to goal, task, or resource standards (Azevedo et al., 2004; Winne, 2001). It is a process which can be triggered either internally (by the student) or externally (by the environment). Highly self-regulated learners are sensitive to both types of stimuli. In case of internal triggering they act on a perceived personal need to check progress and understanding. External triggering

occurs when cues in the environment (e.g., contradictory simulation output) attend students to possible comprehension or task performance failures.

Effective strategies for monitoring include self-questioning and elaboration (Lin & Lehman, 1999). Self-questioning such as "Do I understand what I am doing?" and "How does this result compare to what the assignment says" assists students in comparing the current learning states to the goals established during planning. Elaboration strategies such as note taking and self-explaining are also utilized effectively by strong self-regulating students, as the process of elaborating often shows discrepancies in knowledge which highly self-regulating students attend to (Chi *et al.,* 1994; Schraw, 1998). Self-questioning and elaboration strategies generate feedback students can use to make metacognitive judgments about their learning. Only if these judgments point at comprehension or task performance failures, highly self-regulating students will enact a new strategy or tactic, or adapt an "in use" strategy or tactic in order to more closely match a goal state (Winne, 2001).

2.3. Evaluation

Evaluation activities entail assessments of learning processes and learning outcomes, as well as generalizations relating these processes and products to a broader context (De Jong, 2006a; Ertmer & Newby, 1996). Evaluation of learning processes involves any reflection on the quality of the students' planning, or how well they executed their plans. Issues highly self-regulating students might address to evaluate their learning include hypotheses plausibility, representation effectiveness, experimentation systematicity, exploitation of surprising results, and adequate comparison of predictions with results (Klahr, Dunbar, & Fay, 1990; Lavoie & Good, 1988)

Standards such as those illustrated are based on goals and task standards set during planning. Evaluation with them sets itself apart from the monitoring which occurs during task execution by looking at products in relation to the entire task. Strong self-regulators might use their overall goal or the task description as a reference point to determine the quality of their products and knowledge gains. In addition, students who generalize learning outcomes or products to a broader context reflect on the link between past and future actions promoting transfer of both domain and metacognitive knowledge to new situations (Von Wright, 1992).

3. Problems and solutions

When high-school students engage in inquiry learning, they perform very few of the activities discussed above. They often have poorly constructed plans, or no plans at all. Manlove and Lazonder (2004, see chapter 3) found that students mostly determined what to do as they went, making only ad-hoc plans to respond to an immediate realization of a current need, rather than taking a systematic or global approach. Such reactive methods of self-regulation are generally ineffective because they fail to provide the necessary goal structure and strategic plans for students to progress consistently and monitor and evaluate their learning effectively (Zimmerman, 2000).

A process model might help overcome these planning problems (Lin & Lehman, 1999). Process models give students a global understanding of the task by outlining the stages an expert would go through in performing the inquiry task at hand. A process model thus conveys the top level goals in the hierarchy. It can be supplemented with more specific goals within each of the phases, thus providing students with input to establish strategic plans, and standards for monitoring and evaluating their learning. Process models and goal hierarchies were applied successfully in the Thinker Tools curriculum (White & Frederiksen, 1998), and learning environments such as ASK Jasper (Williams, Bareiss, & Reiser, 1996) and Model It (Jackson *et al.,* 1996).

The problems high-school students have with monitoring are threefold. First, most student fail to recognize they do not understand something (internal triggering) and often are unaware of environmental cues (external triggering) which can provide feedback points for monitoring (Chi et al., 1994; Davis, 2000; Ertmer & Newby, 1996). Secondly, even if students identify comprehension failures, they often do not express a detailed understanding of specifically what they do not understand (Manlove & Lazonder, 2004, see chapter 3). Finally, the few students who manage to become aware at a detailed level that they are experiencing a comprehension or task performance failure often do not have the strategies or tactics needed to fix their problems (Schraw, 1998).

Research has shown that both the quantity and the quality of students' monitoring activities can be enhanced by explicit prompting and direct strategy use feedback. Software cues (e.g., pop-ups) can point students to features of the learning environment which can be used for monitoring, and encourage students to write down the results of monitoring in a note (Butler & Winne, 1995). Self-explanation prompts ("What is meant by 'a relationship' between two variables?") can help students detect and elaborate comprehension problems within note content (Davis, 2000). Reasons-justification prompts ("How did you come up with these

relationships?") can assist students in judging the effectiveness and appropriateness of the procedures they utilized in their inquiries (Lin & Lehman, 1999). Proposing specific strategies for comprehension and task performance failures will also assist students in the final phase of monitoring (Schraw, 1998).

The difficulties high-school students have with evaluating are very similar to the problems encountered during monitoring. Students typically are unaware of the issues they should attend to in evaluating learning processes and outcomes, or the way these issues should be addressed in their evaluations. For example, Schauble, Klopfer, and Raghavan (1991) showed that students hardly reflect on the experimental setup or how methodological issues relate to the research question. Chinn and Brewer (1993) reported that students tend to discount results which are inconsistent with their expectations, and Njoo and De Jong (1993) found that students hardly generalize their learning processes and outcomes to different situations.

Prompting has been found to be as successful in advancing evaluation type activities as it has been to promote monitoring. White and Frederiksen (1998) utilized self-reflective assessments to prompt evaluative activities. These assessments included criteria and rating scales to assist students in assessing their learning processes and products. Self-assessments can be integral to report writing. Lab reports have been a common way for students to report conclusions in science classrooms (White et al., 1999). To assist them in writing their reports, students could be given a report template which augments the process model by unpacking the goals and sub-goals associated with each step, and provides issues and suggestions against which learning processes and products can be evaluated.

4. Investigating regulative tool support

The solutions above propose ways to assist high-school students in planning, monitoring, and evaluating their inquiry learning processes and products through online tool support. The effectiveness of these regulative scaffolds was evaluated in an empirical study wherein students performed a scientific inquiry task. Students utilized the Process Coordinator (hereafter PC) to regulate their inquiry. Students in the experimental condition (PC+) had access to a "full" version of this tool. It included a process model and preset goal hierarchy to support planning, as well as hints, cues, and prompts to promote monitoring through note taking. A separate report template with embedded suggestions for structure and content from which students could develop quality criteria was available for evaluation. Students in the comparison condition (PC–) received an "empty" support tool which contained none of the regulative support

measures available to PC+ students. Instead, the PC– equipped students with an electronic facility to set their own goals, take notes, and structure their reports however they deemed appropriate. Given these differences in regulative support, students in the PC+ condition were expected to achieve higher learning outcomes and use the PC more often to plan, monitor, and evaluate than PC– students.

5. Method

5.1. Participants

Seventy students (30 males and 40 females, aged 16-18) from three international secondary schools in the Netherlands participated in the study. Based on a review of school curricula, and teacher statements, none of the students were familiar with fluid dynamics, the topic of the inquiry activity. Students were classified by their teachers as high, average, or low-achievers based on their science grades. (Student grades themselves were not available due to student record confidentiality). Participants of different achievement levels were randomly grouped into medium-range mixed-ability dyads. Medium range heterogeneous ability grouping promotes more productive conversations during science learning (Gijlers & De Jong, 2005), peer guidance (e.g., Webb, Nemer, & Zuniga, 2002), and equality of participation (Webb, 1991). Dyads thus comprised either a high and average achiever, or an average and low achiever. Given the fact of within-class grouping, 6 medium achievers and 4 high achievers had to be grouped homogeneously. All 35 dyads were then randomly assigned to the PC+ condition (n=20) or the PC– condition (n=15). Preliminary checks revealed no between-condition differences based on achievement level ($L\chi^2$ (4, N=35)=2.80, p=.59).

5.2. Materials

Dyads in both conditions worked on an inquiry task within fluid dynamics which invited them to discover which factors influence the time to empty a water tank. This task was performed within Co-Lab, an inquiry learning environment in which dyads could experiment through a computer simulation of a water tank, and express acquired understanding by making a runnable system dynamics model (see chapter 2 for a description of Co-Lab). By judging model output against the simulation's results, students could adjust or fine-tune their model and thus build an increasingly elaborate domain understanding. Helpfiles explained the operation of the tools in the environment and presented domain information that was too difficult to infer from interactions with the simulation. These files covered physics topics such as "Torricelli's Law" and "water volume" as well as information about system dynamics modeling variables and relationships. Within the modeling help files, information about the domain was often mixed with procedural

information related to the operation of the model editor. The same help files were available in both conditions.

The PC supported dyads in regulating their inquiry learning process. Dyads in the PC– condition received an "empty" version of this tool which contained *no* process model, preset goal hierarchy, goal descriptions, hints, cues, prompts, or report template. The PC– was functional in that students could use it to set, monitor, and evaluate their own goals. Dyads in the PC+ condition were given a "full" version of the PC. This tool contained a process model, a preset goal hierarchy, and goal descriptions which outlined the phases students should process in performing their inquiry (see Figure 5-1). Each goal came with one or more hints students could view by clicking the "Show hints" button. Hints proposed strategies for goal attainment. Doing so required students to click the "Take or edit notes" button to open up a note taking form. As explained in the introduction, prompts were written based on Davis (Davis, 2000, 2003) description of self-explanation prompts (e.g., "Which variables are you most and least sure have an effect on the time it takes to empty a pool?"), and Lin and Lehman's (1999) description of reason justification prompts (e.g., "For the variables you are most sure have an effect, why do you think so?"). Each note form contained one of each type of prompt to stimulate students to check their comprehension and provide evidence for it. Cues reminded students to take notes. Cues appeared as pop-ups in the environment, either when students had not taken a note for 10 minutes or when they switched to a different activity. Since imposed strategy use can be counterproductive and can be seen as an extra cognitive burden (Lan, 2005), students were not forced to make a note in response to a cue. Notes were automatically attached to the active goal and could be inspected by clicking the "History" tab. As the right image of Figure 5-1 shows, this action changed the outlook of the PC such that it revealed the goals and the notes students attached to them in chronological order.

Students in both conditions received a simple text editing tool to write their final reports. This report editor was embedded within the environment and enabled students to copy the contents of their notes into their reports. Lab report writing was a common practice in the participating school's science classes. As such all students were familiar with what a lab report should contain. PC+ dyads were given a report template, which served as a reminder of the structure of a lab report and offered issues and suggestions for content which students could use to reflectively evaluate their learning processes and products. It was predicted that the presence of the template would promote more structured and elaborate lab reports. PC– dyads were not given this template but were informed that they would be writing a lab report within the PC–introduction and in the task assignment.

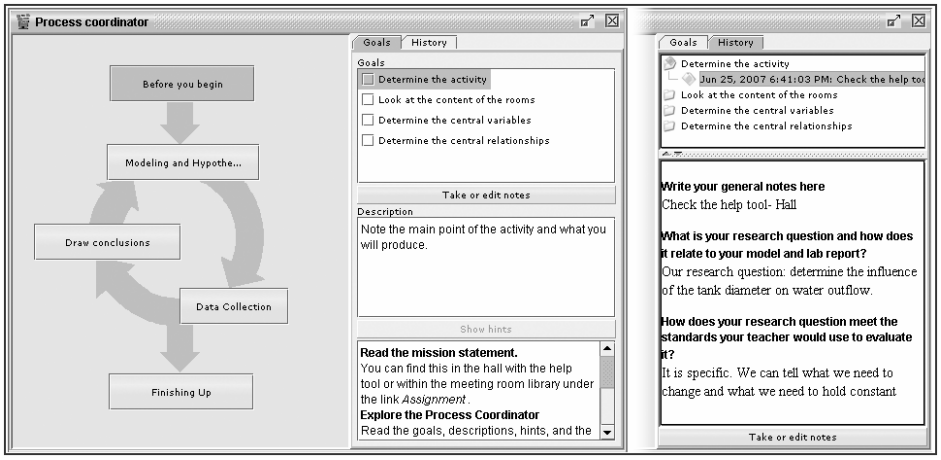


Figure 5-1.Goal tree view (left) and History view (right) of the PC+

5.3. Procedure

The experiment was conducted over five 50-minute lessons that were run in the school's computer lab. The first lesson involved a guided tour of Co-Lab and an introduction to modeling. During the guided tour students in both conditions were taught to plan, monitor, and evaluate their learning with the version of the PC tool they would receive. The modeling tutorial familiarized students with system dynamics modeling language and the operation of Co-Lab's modeling tool. It contextualized the modeling process within a common situation: the inflow and outflow of money from a bank account. Students completed the modeling introduction individually within twenty minutes. In the next four lessons students worked on the inquiry task. They were seated in the computer lab with group members face-to-face in front of one computer. Students were directed to begin by reading the assignment, to use the PC tool for regulation and to refrain from talking to other groups. At the beginning of each lesson the experimenter reminded the students to use the PC tool. At the beginning of lesson 4, students were told to complete their modeling work, and at the beginning of lesson 5 they were told to stop their modeling work and complete their lab reports. Assistance was given on computer technical issues only.

6. Coding and scoring

6.1. Learning outcomes

Learning outcomes were assessed from the dyads' final models and lab reports. As models convey students' conceptual domain knowledge from variable and relationship specification (White et al., 1999), a model quality score was computed from the number of correctly specified variables and relations in the models (see Figure 4-2 target model in chapter 4) . One point was awarded for each correctly named variable,

with “correct” referring to a name identifying a factor which influences the outflow of the water tank (i.e., water volume, tank level, tank diameter, drain diameter, outflow rate). One additional point was given in case a variable was of the correct type (i.e., stock, auxiliary, constant). Concerning relations, one point was awarded for each correct link between two variables. Up to two additional points could be earned if the direction and type of the relation was correct. The maximum model quality score was 26. All models were scored by two raters; inter-rater reliability estimates (Cohen’s κ) for variables and relations were .95 and .91 respectively.

A rubric was developed to evaluate the structure and content of students’ lab reports. Both measures were scored for completed reports only. Report structure concerned the logical organization of the students’ writing, and was indicated by the presence of sections specified in the report template (i.e., introduction, method, results, conclusion, and discussion). One point was awarded for each included section, leading to a maximum score of 5 points. A report content score represented the extent to which students’ reports addressed the topics of evaluation subsumed under each section in the report template. Examples include “state your general research question”, “list your hypotheses”, “present data for each hypothesis”, and “describe pros and cons of your working method”. The template contained 11 topics, and the report content score reflected the number of topics included in a report. All reports were scored by two raters; inter-rater agreement reached 85.14% for report structure and 86.49% for report content.

6.2. Regulative activities

Analyses of regulative activities focused on students’ use of the regulative scaffolds. All data were assessed from the log files. The scope of participants’ regulative activities was indicated by the duration and frequency of PC and report editor use. At a more detailed level, participants’ actions with these tools were classified as being either a planning, monitoring, or evaluation act. Given the differences in regulative support across conditions, the coding of these measures showed some cross-condition variation as well.

Planning was defined as the number of times participants’ added a goal (PC– condition only), and viewed a goal and its description (both conditions). PC actions associated with monitoring were note taking and note viewing. Note taking concerned the number of times participants created a new note or edited an existing note; note viewing was the number of times participants checked existing notes. Note taking instances of PC+ dyads were further classified as either spontaneous or cued. The number of instances in which participants viewed hints was also indicative of monitoring in the PC+ condition. Dyads in the PC– condition had no access to hints, making the help files their only source of

assistance. Instances of helpfile usage were counted for both conditions. Evaluation was assessed from the number of times students viewed the report template, and could be assessed in the PC+ condition only.

6.3. Data analysis

Data analysis focused on between-group differences in regulative activities and learning outcomes. Kolmogorov-Smirnov tests were performed to test the normality assumption. Levene's tests were used to check the homogeneity of variances among cell groups for all dependent variables. In case of homogeneity, one-way univariate ANOVA's were used to examine the effect of the regulative scaffolds on that variable. Variables with unequal variances were analyzed by means of *t* tests with separate variance estimates. In case of significance, the standardized difference between groups (Cohen's *d*) was computed to indicate the magnitude of effects. Correlational analyses were performed to examine the relationships between tool use for regulative activities and learning outcomes.

To ensure that observed differences were attributed solely to the presence and use of regulative scaffolds, all of the above analyses were re-run using the dyads' achievement level as an additional factor. Achievement was indicated by the teacher-assigned level of the highest achieving group member. As none of the analyses for regulative activities revealed a significant main effect of achievement level or a significant condition × achievement interaction, these result were not reported for the sake of readability. Achievement level did affect learning outcomes however, so two-way univariate ANOVAs were reported for the analyses of the dyads final models.

7. Results

The data summarized in Table 5-1 shows that overall dyads in both conditions spent a comparable amount of time on the inquiry task ($F(1,33)=.07$, $p=.80$). However, participants from both conditions organized their time differently, particularly with respect to balancing task performance and regulation. On average, PC+ dyads used the PC about three times as long and twice as much as PC– dyads did. Both differences were statistically significant (time: $t(24.01)=3.78$, $p<.01$, $d=1.21$; frequency: $t(22.81)=2.08$, $p<.05$, $d=0.66$). PC+ dyads also activated the report editor more often than PC– dyads, but this difference did not reach significance ($F(1,33)=2.60$, $p=.12$). Nor did comparison between the conditions on report editor use time ($F(1,26)=.01$, $p=.92$).

Table 5-1. Summary of overall learning activities and outcomes

	PC+		PC–	
	M	*SD*	*M*	*SD*
Time (min.)				
Time on task	172.53	19.26	175.42	44.69
Time using PC	26.41	18.79	9.45	6.06
Time using report editor [a]	28.54	10.23	29.03	15.59
Frequency of tool use				
PC	28.75	28.48	14.87	7.95
Report editor	16.75	13.11	10.80	6.48
Learning outcomes				
Lab report structure [b]	4.33	.62	3.45	.69
Lab report content [c]	7.40	1.64	4.45	1.44
Model quality [d]	11.00	6.05	18.40	5.65

[a] Due to technical difficulties, 4 PC+ and 3 PC– dyads used an external report editor and were removed from the analysis.
[b] Computed for completed reports only, maximum score = 5.
[c] Completed for completed reports only, maximum score = 11.
[d] Maximum score = 26.

Table 5-2 gives a more detailed account of the participants' regulative tool use. As the PC– contained no regulative directions, dyads in this condition had to set their own goals during planning. Goal setting was observed in 12 of the 15 PC– dyads, with scores ranging from 1 to 8 goals (mode=2). PC– dyads could view the goals they added to the PC throughout their inquiry, just like PC+ dyads could view the preset goals in their version of the tool. As shown in Table 5-2, PC+ dyads viewed goals nine times more often than PC– dyads ($t(21.48)=5.39$, $p<.01$, $d=1.72$). Table 5-2 also shows a high standard deviation in the goal viewing scores of the PC+ dyads. Closer examination of the frequencies indicated that PC+ dyads viewed goals 6 to 72 times (median=21).

Concerning monitoring, dyads in the PC+ condition took notes more than twice as often as their PC– counterparts did. Yet this difference was not significant at the .05 level ($t(21.03)=1.82$, $p<.10$, $d=0.35$), which is probably due to a high variability of scores. On average, 9.82 percent of the PC+ dyads' note taking occurred in response to a cue. Still, a mere 3.83 percent of all cues triggered note taking activity, while 5.98 percent of the cues resulted in a regulative action with the PC other than note taking. Despite this activity, actual saved notes by students was very low

Table 5-2. Frequencies of tool use for regulative activities

	PC+		PC–	
	M	*SD*	*M*	*SD*
Planning				
Add goals	–	–	2.53	2.42
View goals	27.70	19.58	3.33	4.37
Monitoring				
Take notes	10.25	14.84	4.07	2.99
View notes	4.95	6.89	3.80	4.83
View hints	4.35	6.05	–	–
View help files	10.60	9.56	21.20	9.17
Evaluation				
View report template	1.20	.83	–	–

and no difference existed between the conditions; the PC+ dyads ended up with an average of 3 saved notes over the course of their inquiry, and the PC- dyads only 2. Due to this lack of evidence, further analysis of student use of the note-template prompts was not deemed fruitful. The scores in Table 5-2 further indicate that viewing the contents of existing notes occurred as often in both conditions ($F(1,33)=.30$, $p=.59$). PC+ dyads viewed the hints 0 to 24 times. The distribution in scores was skewed, with 75% of the dyads viewing 5 hints or less. As hints were not available in the PC–, dyads in this condition could only turn to the help files for assistance. Results showed that they consulted these files more often than PC+ dyads did ($F(1,33)=10.92$, $p<.01$, $d=1.13$).

Central to evaluation activities was report writing. The template that assisted PC+ dyads herein was consulted by 16 of the 20 dyads. The majority of these dyads viewed the template once or twice during the writing process. The outcomes of participants' evaluative efforts differed in favor of the PC+ dyads. As Table 5-1 shows, report structure scores were significantly higher in the PC+ condition ($F(1,22)=9.57$, $p<.01$, $d=1.49$), indicating that PC+ dyads produced better structured reports. Achievement level had no effect on this measure ($F(1,22)=.29$, $p=.60$); the condition × achievement interaction was not significant either ($F(1,22)=.1.47$, $p=.24$). PC+ dyads also gave a more complete account of their inquiry activities and outcomes, as evidenced by higher report content scores. This difference too was statistically significant ($F(1,24)=22.66$, $p<.01$, $d=1.74$). There was no significant main effect of achievement level ($F(1,22)=.05$, $p=83$) and no significant interaction ($F(1,22)=.01$, $p=.92$).

In addition to lab reports, learning outcomes were indicated by the quality of the groups' final model solutions (see Table 5-1). The model quality scores of PC- dyads were significantly higher than those of the PC+ dyads ($F(1,31)=9.98$, $p<.01$, $d=1.26$). Achievement level had no effect on model quality ($F(1,31)=.40$, $p=.53$), but the condition × achievement interaction proved statistically significant ($F(1,31)=6.76$, $p<.05$). Figure 5-2 illustrates how the effect of condition was moderated by achievement level. As these graphs indicate, lower-achieving PC– dyads on average obtained a 10-point higher model quality score than their PC+ counterparts. For higher-achieving dyads this difference was 1.1 point.

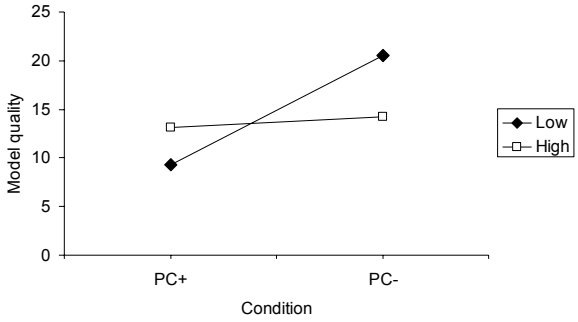


Figure 5-2.Model quality scores as a function of instructional condition and achievement level

Correlational analyses further revealed that higher model quality scores were associated with lower instances of goal viewing and note taking (see Table 5-3). The correlation between model quality and helpfile viewing approached significance ($p=.07$), suggesting that dyads who consulted the help files more often also built more accurate models. A reverse pattern was obtained for both lab report scores, with significant positive correlations for frequencies of regulative tool use, and negative correlations for instances of helpfile viewing.

8. Discussion

This study examined the effects of regulative tool support on students' regulative activities and learning outcomes. Students who had access to a scaffold with regulative directions were expected to use the tool more often for regulation, and to construct better domain models and write better lab reports than students who received an "empty" version of this tool.

Table 5-3. Correlations between tool use for regulative activities and learning outcomes in both conditions

	Model quality	Lab report structure	Lab report content
View goals	−.54**	.62**	.51**
Take notes	−.40*	.54**	.28
View notes	−.05	.58**	.40*
View help files	.31	−.59**	−.19

* $p<.05$ (two-tailed) ** $p<.01$ (two-tailed)

Results for regulative activities generally confirm the hypotheses on tool use and time measures. PC+ dyads used their PC more frequently and for a longer amount of time. In terms of tool use, two activities in particular stand out as differing from the PC– condition: goal viewing and note taking. PC+ dyads viewed more goals than their PC– counterparts. While PC– dyads set very few goals –and thus had fewer goals to view– the process model and goal hierarchy was the most used feature for PC+ dyads, suggesting that students might follow and utilize goal lists more often then setting or revisiting their own goals. PC+ dyads also had higher note taking frequencies but this difference was not supported by standard measures of statistical significance. In addition, almost 10 percent of the notes in the PC+ condition were taken in response to a cue, and about 6 percent of the cues triggered other PC actions such as goal viewing. In view of these findings it is probably fair to conclude that cues have a moderate but positive contribution to regulative tool use in general and note taking in particular.

The hypothesis with respect to learning outcomes is partially supported by the results. As expected, both low and high-achieving PC+ dyads produced structurally better lab reports and gave a more complete account of their inquiry activities than PC– dyads. The fact that most PC+ groups used the report template during the writing process may have contributed to this effect. Positive correlations between lab report scores and regulative activities further indicate that PC+ students who viewed more goals and took more notes were given a head start on their lab report work.

Contrary to expectations, PC– dyads created significantly better models than their more supported counterparts. The significant condition × achievement further indicates that this conclusion applies to low-achieving dyads only. Two factors may have contributed to this unexpected outcome. First, given the substantial differences in time spent on regulative tool use, it seems plausible that using a fully specified PC

simply takes too much time away from modeling work. This seems pertinent to low-achieving dyads who, due to their lower levels of domain proficiency, may require more time to grasp the regulative directions offered by the PC. Secondly, PC– dyads as a whole viewed help files more often than PC+ dyads, and helpfile viewing was positively associated with model quality (significant at the .10 level). As the help files contained domain and model-specific information, it may have been more useful for modeling than the process-oriented regulative support. PC– dyads who, in absence of regulative support, focused on the help files thus may have had an advantage in their modeling work. These findings also suggest that PC+ students relied on regulative support more than domain support.

The implied dichotomy between choosing appropriate scaffolds for different learning outcomes may account for the discrepancy between this study's findings and those mentioned in the introduction where student learning gains benefited from regulative support (Manlove, Lazonder, & De Jong, 2006, see chapter 4). Although the PC+ *did* refer students to specific help files within the hints, it apparently did not go far enough in stressing that domain support would enhance their modeling work. This points to a need for scaffolds designed for different purposes to work in tandem with each other. One way to make this possible is to link regulative support more closely to domain supports and activities. Future research might investigate whether such integrated support yields higher use and perceived usefulness than stand-alone regulative support.

Although the present study was not designed to capture students' views on the usefulness of the PC, the high data variance across all measures indicates that its use was widely divergent. This could mean that students are not equally compliant in regulative scaffolding use –nor perhaps should that be the expectation. After all, students enter a learning environment with a variety of learning skills, prior knowledge and learning styles. As the analysis related to dyad achievement shows, prior knowledge did impact student's model quality. Although future research which gathers specific pre-test measures of ability might illuminate this factor more precisely, the high variance in scores could indicate that the use and usefulness of the PC depends on the synergy existent between students' existing regulative abilities and knowledge. Higher-achieving dyads may use the tool less, and find it less useful because the regulative directions conflict with their own regulative strategies; lower achieving dyads may be overwhelmed with the comprehensive support the PC supplied. In the future, adaptive and non-intrusive support structures, although difficult to create, seem called for. Suggestions for how to achieve these two qualities are further elaborated below.

Non-intrusive support for regulation could imply that students perform regulative activities as a "natural" course of conducting their inquiry. The format of a support feature and its intended outcome might thus play a role in its perceived usefulness. Monitoring through note taking is a good

example of how this may be achieved. Note taking in this study was situated away from the simulation and model editor. Provision of an annotation function to simulation output or the ability to add comments to models might be a more natural, less obtrusive way to monitor task performance and comprehension. The non-intrusiveness of note taking could be further enhanced by adapting its representation to the representation used in the inquiry activity. The system dynamics models students had to create rely almost exclusively on a graphical representation of information. The PC+ supports for modeling however were text-based. The negative correlation between note taking activity and model quality scores suggests that text-based note formats could be inconsistent with or unfruitful for graphical modeling work.

Evidence supporting this notion can be gleaned from the work of Gijlers and De Jong (2005), who found that supplying students with a concept map tool significantly enhanced their understanding of structures and interrelations in the domain. The work of Larkin and Simon (1987) and Van der Meij and De Jong (2006) point to the idea that different types of representations are useful for different activities pertaining to "…their representational and computational efficiency" (p. 200). The processing and use of different representations is also accompanied by an assumption of limited capacity, meaning that the amount of representational processing that can take place within information processing channels for visual or verbal information is extremely limited (Mayer, 2003). Thus note taking which is closer to the graphical nature of modeling may be more beneficial than plain text-based note taking. Future research should look at adapting note representations to task characteristics especially with the rather innovative learning outcomes often found in inquiry learning environments.

The issue of intrusiveness certainly applies to the use of cues to stimulate students to take notes. In this study the timing of cues was based on the prior work of Manlove and Lazonder (2004, see chapter 3), who found that natural monitoring points occur at virtual room changes within the environment (which mark the end of an activity), but also that students often spend long periods of time in one room. Timing the cues for every ten minutes came from considering that without frequent room changes or note taking (as the cue times were reset if students took a note) students would receive on average 5 cues per session. So despite efforts to minimize intrusion, the relatively low cue responses in this study suggest that students may still have seen them as interruptive. Future research should investigate the appropriate timing and placement of cues and their effect on note taking to see when and where they help rather than hinder work from a student's point of view.

However, the use of cues and regulative supports in general may have been influenced by the fact that students performed the inquiry task in dyads. Collaboration was used because it is a common form of learning

during hands-on science activities in secondary schools. Although not an object of study in this research (students in both conditions worked collaboratively), collaboration may have had an effect on students' regulatory or help seeking behavior. A study by Manlove, Lazonder, and De Jong, (2006, see chapter 4) revealed no differences in the amount of regulative talk between PC+ and PC– groups, but in a broader sense, the presence of a peer may have lowered the frequency of tool use in both conditions. For example, students may not always consult the PC or help files if they can just ask their partner for help. The magnitude of this effect could be examined by comparing regulative tool use during collaborative and individual inquiry learning.

Overall the results of this study point to implications for practice. The educational benefits of regulative scaffolding depend on factors such as amount of domain and process support and their perceived match to learning activities, outcomes and context. Teachers who wish to use technology-enhanced inquiry learning environments should assist students in the appropriate selection of supports for task activities. They may, for instance, point out that help files might be more beneficial for modeling activities but that responding to prompts within notes will assist them in report writing. Educational designers also need to be aware of this need to "regulate regulative tool use". Designs which situate regulative support closely to task activities and make apparent how their use benefits learning outcomes may be utilized more frequently and seen as more beneficial by students. In this way regulation and its role within inquiry learning environments might strike a balance between being salient, and implicit when facilitating domain and process knowledge construction in science learning.

6. Collaborative versus individual use of regulative scaffolds[8]

Abstract

The use of scaffolds to plan, monitor, and evaluate learning within technology-enhanced inquiry and modeling environments are often little used by students. One reason may be that students often work collaboratively in these settings, and their group work may interfere with the use of regulative supports. This research compared the use of regulative scaffolds within an inquiry and modeling environment by Pairs and Single students. Pairs were predicted to make less use of regulative scaffolds than Singles. To validate this assumption, 42 high-school students worked either individually (n=18) or in Pairs (n=12) within an inquiry learning environment. Two regulative scaffolds were used by both conditions to assist them with planning, monitoring, and evaluating their investigative efforts: the Process Coordinator (PC) and a Lab Report Template. Results showed that Pairs achieved significantly higher learning outcomes than individual students. And, although there was a strong trend of increased regulative tool use by individual students, the frequency and duration of regulative tool use did not differ significantly between conditions. Implications of these effects for regulative scaffold design and use are discussed and suggestions for future research are advanced.

[8] This chapter was adapted from Manlove, S., Lazonder, A.W., & De Jong, T. (in press), Collaborative versus individual use of regulative software scaffolds during scientific inquiry learning. *Interactive Learning Environments*.

"Reading the primer had always meant racting with other characters in the book while also having to think her way through various interesting situations" (Stephenson, 1995, p. 351).

1. Introduction

Research has shown that students who plan, monitor, and evaluate well during learning, tend to have better learning outcomes than students who do not within technology-enhanced learning environments (Azevedo et al., 2004). Students adept at these regulative processes create goals and sub-goals during planning which become cognitive strategies for task fulfillment. Coupled to these cognitive strategies are standards against which students can monitor task progress and quality of understanding (Butler & Winne, 1995). Ultimately this recursive process is thought to lead students to points of evaluation, where they assess both their learning processes and products to determine if different strategies need to be employed or to finalize the task (Pintrich, 2000; Zimmerman, 2000). These cognitive regulation processes are thought to be critical for effective knowledge integration where students must expand a repertoire of ideas, distinguish and make links between ideas, as well as identify weaknesses in understanding (Davis, 2003; Linn, 1995)

Unfortunately many students struggle to effectively plan, monitor, or evaluate their own learning, as evidenced by the typically low instances of regulative activities found in their learning. Low levels of self-regulation are particularly apparent in inquiry learning – a pedagogy in which learners induce the characteristics of a domain through genuine scientific processes of orientation, hypothesizing, experimentation, creating models and theories, and evaluation (De Jong, 2006a; De Jong & Van Joolingen, 1998; Land, 2000; Manlove & Lazonder, 2004). Learners have difficulty with these processes and require support. Therefore inquiry learning environments typically incorporate cognitive tools and scaffolds that support students, particularly with regulation of their inquiry work.

Research has consistently shown that regulative scaffolds have a positive impact on learning outcomes. Kauffman (2004) and Veenman, Elshout, and Busato (1994; Veenman et al., 1994), demonstrated positive effects with the implementation of regulative prompts. Kaufman's research found significant effects with self-monitoring and self-efficacy prompts in a Webquest© environment about educational measurement. He found that students supplied with prompts outperformed students who didn't receive them on post-tests. He also found that students supplied with a matrix organizer for their notes outperformed students who took "free form" (no imposed structure) notes on post-tests. Veenman et al., utilized system-generated prompts to direct students' attention to the regulatory aspects of the inquiry task. Their study showed that prompted students outperformed unprompted students on regulative measures such as

orientation, systematicity, and evaluation activities as well as on post-test measures of learning outcomes. Kramarski and Gutman (2006) found that students supplied with questions to promote regulation and metacognition in a mathematics e-learning environment outperformed control students on transfer problems and mathematical explanations in the post test. Manlove, Lazonder and De Jong (2006, see chapter 4) examined the effectiveness of a regulative support tool that scaffolded students' planning and monitoring activities through goal hierarchies, note taking facilities, and hints. Students who had access to these supports outperformed students who used a version of this tool from which all supportive content was removed.

Although the potential of regulative tool support appears quite compelling, its effectiveness has been stymied by one persistent problem: just because a tool is available, does not mean students will use it, or use it effectively (Land, 2000; Oliver & Hannafin, 2000). In fact, a meta-analysis by Clarebout and Elen (2006) substantiated that cognitive tools which support performance and information seeking are generally used more than tools designed for elaboration or regulative support. A similar finding was made in a recent study of Manlove, Lazonder and De Jong (in press, see chapter 5) which found low instances of regulative tool use by all participants despite the inclusion of cues designed to promote increased tool use within the experimental group. A related study by these authors revealed that students also tended to abandon regulative supports once orientation to the activity had been achieved (Manlove et al., 2006, see chapter 4). Liu and Bera's (2005) work illustrates that this problem extends to the use of tools to support cognitive processes as well. One reason for this low and inconsistent use of regulative supports in both of Manlove et al.,'s (2006, in press, see chapters 4 and 5) studies may be that students worked in pairs. This raises the question of how collaboration may have affected students' behavior with regulative supports.

Probably the most well-documented benefit of collaboration is that it promotes learning. Research has consistently shown that students learning in small groups (either with or without a computer) achieve higher learning gains compared to students who learn individually. The magnitude of these effects was shown in several meta-analytical studies (Cohen, 1994; Lou et al., 2001; Lou et al., 1996). In small-group learning with computers, Cohen and Scardamalia (1998) pointed out that these learning benefits are due to the fact that "conversations around the computer represent significant learning moments" (p.94). Such learning moments include opportunities for students to engage in conceptual change and improved understanding through discourse with peers who have differing ideas and perceptions (Howe, 1991).

Collaboration also entails an implicit obligation to make sense to one's partner (Teasley & Roschelle, 1993). The presence of a classmate could thus be a natural impetus for students to make implicit regulatory skills of

planning, monitoring, and evaluation explicit and salient. That is, students working together are assumed to expound their plans to approach the learning task, monitor each other's actions and understanding, and evaluate outcomes of their work (Chi *et al.,* 1989; Chi et al., 1994; Teasley, 1995). Research has borne this out. Lazonder (2005) for example found that pairs performed relatively more regulative activities and outperformed single students on web search tasks. Teasley (1995), who compared pairs and singles in a spaceship simulation game, also observed higher instances of planning (i.e., strategy selection) and more coordinating activities in pairs compared to single students.

It stands to reason that these differences in regulative activities impinge upon learners' need for regulative support. Yet research seeking to describe tool use from an individual versus collaborative perspective is scant, and the studies that do exist almost exclusively focus on elaboration type scaffolds which help students access simulations, additional explanations, practices, and information. Crook, Klein, Jones, and Dwyer (1996) for instance found that individual students working with a CBI program selected more options (as the scaffolds were called) than pairs did. A similar study by Crook, Klein, Savenye, and Leader (1998) failed to reproduce this effect, but did show that pairs selected significantly more elaborative feedback items when compared to singles. Bera and Liu (2006) examined group tool use within "Alien Rescue", a hypermedia environment which included tools for information seeking (data-bases), regulation (note-book and bookmark features), simulations, and hypothesis testing. They grouped usage into high, medium, and low tool use clusters. Their findings show that students who used these tools the least outperformed both average and high tool users on factual as well as applied knowledge tests. Interestingly the authors speculate in their discussion, "One possible explanation may be that, as opposed to groups that visit and re-visit tools with more frequency, groups in the low cluster rely on each other rather than on the tools" (p. 315). Harskamp and Ding (2006) additionally found that collaborative groups outperformed individuals in their examination of group and individual use of hints in a CSCL math environment. However, a comparison of the two collaborative groups (with hints, and without) yielded no significant difference, implying that the added value of regulative scaffolds coupled with collaborative learning is not at all clear.

The research discussed above points to questions about how collaboration might impact regulative tool use. The work of Teasley (1995) and Chi et al., (1994) suggests that it is within the conversations of collaborating students that regulative scaffolds are possibly "supplanted". While this would be valuable research for the future, a logical first step would be to ascertain that there is an actual difference between groups and individuals in terms of regulative tool use. The present study therefore compared regulative tool use between Pairs and Singles within an inquiry learning environment. The presence of a peer was predicted to lower the frequency

of regulative tool use. Pairs were further expected to have better learning outcomes than Single students.

2. Method

2.1. Participants

Forty-two students (27 males and 15 females, aged 16-18) participated in this study. The students were enrolled in an upper-level physics course at a rural university town high school in the United States. The course included an introductory fluids unit taken five months prior to conduction of this research. This unit covered basic theoretical and conceptual knowledge related to the physics of fluids but did not involve modeling. Questions related to this unit were also included in annual comprehensive course examinations held one week prior to student participation in this study. Thus the students had some prior knowledge with the domain of the inquiry activity, fluid dynamics, but no familiarity with construction of system dynamics models.

The teacher supplied physics class ranks based on current course grades for each participant. Following the classification of Webb (1991), these ranks were then transformed into high, medium, or low achievement levels in science. The upper and lower 25% of the ranks were assigned to high and low achievement levels. Students in the middle 50% were assigned to average achievement levels. Within these achievement level groups, the number of students required for each condition was determined to ensure an adequate distribution across conditions for achievement levels (which is not reflected by the reported sample due to absenteeism). Students were then randomly assigned so that two thirds of the students in a class were placed in the collaborative condition and one third worked individually. Within the collaborative condition, Pairs were further matched by achievement to ensure they included either a high and average achiever, or an average and low achiever. The results of this process lead to 12 Pairs and 18 Single students (N=42).

2.2. Materials

Students worked on an inquiry task within fluid dynamics to discover which factors influenced the time to empty a water tank. This task was performed within Co-Lab, an inquiry learning environment in which students can experiment with a computer simulation of a water tank, and express acquired understanding by making a runnable system dynamics model (see chapter 2 for a description of Co-Lab). Students could adjust or fine-tune their models to build elaborate domain understanding by evaluating model output against simulation results. Help files explained the operation of the tools in the environment and presented domain

information that was too difficult to infer from interactions with the simulation.

The Process Coordinator (hereafter PC) supported Pairs and Singles in regulating their inquiry learning process. This tool contained a process model, a preset goal hierarchy, and goal descriptions that outlined the phases students should process in performing their inquiry (see Figure 6-1). Each goal came with one or more hints students could view by clicking the "Show hints" button. Hints proposed strategies for goal attainment. Note taking required students to click the "Take or edit notes" button to open up a note form. Self-explanation prompts (e.g.," How is your hypothesis reflected in the experimental setup?") and reason justification prompts (e.g., "Why did you compare model data with simulation output?") were added to this form to stimulate students to check and monitor their comprehension. Cues reminded students to take notes and appeared as pop-ups in the environment. They appeared either when students had not taken a note for 10 minutes or when they switched to a different virtual room in the environment which signified a change of activity or focus. Since imposed strategy use can be counterproductive (Lan, 2005), students were not forced to make a note in response to a cue. Notes were automatically attached to the active goal and could be inspected by clicking the "History" tab. As the right image of Figure 6-1 shows, this action changed the outlook of the PC such that it revealed the goals and the notes students attached to them in chronological order.

Students also received a simple text editing tool to write their final reports. This report editor was embedded within the environment and enabled students to copy the contents of their notes to their reports. A report template was available as a regulative support through the help file

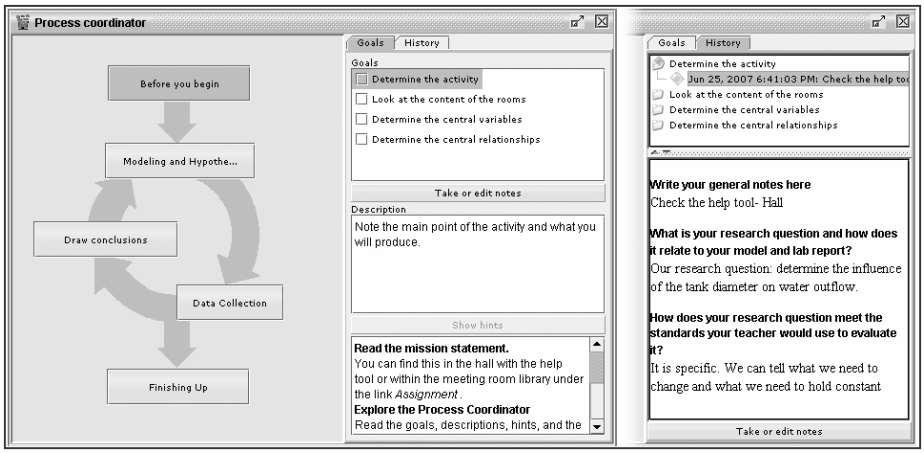


Figure 6-1. Goal tree view (left) and History view (right) of the PC used by both conditions

system that elucidated the structure of the report and offered issues and suggestions for content which students could use to evaluate their learning processes and products.

2. 3. Procedure

The experiment was conducted over five 50-minute lessons that were run in the school's computer lab. The first lesson involved a guided tour of Co-Lab and an introduction to modeling. During the guided tour students were given an overview of Co-Lab's tools and were shown how to use the PC and the cues to assist them in regulating their inquiry work. The modeling tutorial familiarized students with system dynamics modeling language and the operation of Co-Lab's modeling tool. It contextualized the modeling process within a common situation: the inflow and outflow of money from a bank account. Students completed the modeling introduction individually within twenty minutes. In the next four lessons students worked on the inquiry task. Pairs were situated in front of one computer and collaborated face to face. Individual students were assigned seating as far away from the Pairs as possible to prevent them from overhearing collaborative discussions. Students were directed to; begin by reading the assignment, use the PC tool for regulation and to refrain from talking to other students (outside their Pairs). At the beginning of each lesson the experimenter reminded the students to use the PC tool. At the beginning of lesson 4, students were told to complete their modeling work, and at the beginning of lesson 5 they were told to stop their modeling work and complete their lab reports. Assistance was given on computer technical issues only.

3. Coding and scoring

3.1. Learning outcomes

Learning outcomes were assessed from final models and lab reports. As models convey students' conceptual domain knowledge from variable and relationship specification (White et al., 1999), a model quality score was computed from the number of correctly specified variables and relations in the models. One point was awarded for each correctly named variable, with "correct" referring to a name identifying a factor that influences the outflow of the water tank (i.e., water volume, tank level, tank diameter, drain diameter, outflow rate). One additional point was given in case a variable was of the correct type (i.e., stock, auxiliary, constant). Concerning relations, one point was awarded for each correct link between two variables. Up to two additional points could be earned if the direction and type of the relation was correct. The maximum model quality score was 26. All models (a total of 30) were scored independently by two raters; inter-rater reliability estimates (Cohen's κ) for variables and relations were .95 and .91 respectively.

A rubric was developed to evaluate the structure and content of students' lab reports. Report structure concerned the logical organization of the students' writing, and was indicated by the presence of sections specified in the report template (i.e., introduction, method, results, conclusion, and discussion). One point was awarded for each included section, leading to a maximum score of 5 points. A report content score represented the extent to which students' reports addressed the topics of evaluation subsumed under each section in the report template. Examples include "state your general research question", "list your hypotheses", "state your results in relationship to your hypothesis and model work", and "evaluate your working method". The template contained 14 topics, and the report content score reflected the degree of elaboration for each topic on a scale of 0 to 2. To illustrate, for the introduction section students were asked to describe the role modeling played in answering their research question(s). A score of 0 indicated that the students did not address how modeling would be used at all. A score of 1 indicated that students stated "how" modeling would be used but not "why" (e.g., "We made an electronic model to express our understanding"). A score of 2 indicated that students showed an understanding of the model as being an expansion of the water tank simulation and why it is useful in their research (e.g., "Modeling work plays an important role in this research because we can change multiple variables to check for different water tank dimensions not available in the tank simulation"). Twenty percent of the total lab reports were scored by a second rater; inter-rater agreement for report content was 75.77%. In the study depicted in chapter 5, the same coding was used for report structure where inter-rater agreement reached 85.14%

3.2. Regulative tool use

All data were assessed from the log files. The scope of participants' regulative activities was indicated by the duration and frequency of PC and report editor use. At a more detailed level, participants' actions with these tools were classified as being a planning, monitoring, or evaluation act. Planning was defined as the number of times participants' viewed either a top level inquiry phase or an inquiry phase goal and its description. PC actions associated with monitoring were taking or viewing a note as well as viewing help files. Note taking instances were further examined with respect to student responses to note taking cues and note template prompts. Evaluation was assessed from the number of times students viewed the report template and checked off goals within the PC.

3.3. Data analysis

This study used a between-subjects design with collaboration (Pair, Single) as the independent variable and tool use and learning outcomes as dependent variables. Levene's tests were used to check the homogeneity of variances among cell groups for all dependent variables. In case of

homogeneity, both multivariate and univariate ANOVA's were used to examine the effect of collaboration on that variable. In case of significance, the standardized difference between groups (Cohen's *d*) was computed to indicate the magnitude of effects.

4. Results

According to the data summarized in Table 6-1, Pairs and Singles spent equal amounts of time overall on the inquiry task ($F(1,28)=.02$, $p=.89$). An examination of the mean time for tool use and means for tool activation reveals a general trend showing that Singles used the PC and report editor slightly more with respect to time than the Pairs, however this result was not statistically significant ($F(2,27)=1.38$, $p=.27$). This trend is continued in the data for frequency of tool use. Singles activated the PC, the report editor, and help tool more often than their collaborative counterparts but again these results were not found to be statistically significant. ($F(3,26)=.74$, $p=.54$)

Table 6-1. Summary of overall learning activities and outcomes

	Pairs		Singles	
	M	*SD*	*M*	*SD*
Time (min.)				
Time on task	191.41	16.25	192.54	23.21
Time using PC	25.86	16.20	28.34	12.41
Time using report editor	30.86	9.93	37.98	13.64
Frequency of tool use				
PC	69.25	35.95	81.56	36.57
Report editor	20.50	12.04	23.89	10.60
Help Tool	47.50	10.91	58.22	28.38
Learning outcomes				
Lab report structure[a]	4.33	0.88	4.06	1.21
Lab report content[b]	14.00	3.05	10.61	4.91
Model quality[c]	21.00	3.83	17.28	2.94

[a] Maximum score = 5.
[b] Maximum score =28.
[c] Maximum score = 26.

Table 6-2 gives a more detailed account of participant's regulative tool use. With regard to planning, Singles viewed goals about slightly more often than Pairs but this result, although consistent with the general trend, was not statistically significant ($F(1,28)=.65$, $p=.43$). Single students also engaged slightly more often in monitoring activities such as

activation of the "take note" feature, and viewing saved notes, hints, and help files, but again not to a statistically significant degree ($F(4,25)=.59$, $p=.67$).

Table 6-2. Frequencies of tool use for regulative activities

	Pairs		Singles	
	M	*SD*	*M*	*SD*
Planning				
View goals	56.25	21.82	63.11	23.58
Monitoring				
Take notes	16.00	10.97	21.17	12.51
View notes	8.75	5.87	10.61	7.84
View hints	4.33	5.03	5.22	5.81
View help files	18.75	12.14	22.44	10.86
Evaluation				
View report template	1.92	1.0	1.83	1.15
Goal check	6.75	6.21	6.33	5.24

Singles and Pairs did respond to note taking cues differently. Pairs responded by clicking "no" significantly more often to note taking cues than Singles (85% vs. 71%; $F(1,28)=4.86$, $p<.05$). However the cues did not promote differences in the number of saved notes between the two conditions, with students in both conditions saving on average 9 notes across the five sessions ($F(1,28)=.14$, $p=.71$). Singles responded only slightly more to general (56%), comprehension monitoring (58%), and reason justification (34%) prompts then their collaborative counterparts at 54%, 50%, and 33% respectively. These differences were not found to be significant ($F(3,25)=.41$, $p=.75$).

In terms of evaluative activities such as reviewing the report template and checking off goals there were no differences found between the conditions (F $(2,27)=.04$, $p=1.0$). Both Pairs and Singles viewed the report template at least one time, and checked off goals in the PC an average of six times.

Pertaining to learning outcomes however, Pairs outperformed their Single counter parts as expected. To ensure that these differences were not attributed simply to a higher achieving student within the dyads, analyses for learning outcomes used achievement level as a covariate. The data for lab report structure indicated that both Pairs and Singles included nearly all template sections ($F(1,27)=.35$, $p=.56$). Achievement level did not effect this measure ($F(1,27)=1.73$, $p=.20$). Achievement level did however impact the content of their lab reports ($F(1,27)=8.35$, $p=.01$). After

controlling for this effect, Pairs indeed gave a more elaborate account of their work within lab report content ($F(1,27)=4.68$, $p<.05$, $d=0.83$). They also had significantly better models ($F(1,27)=9.07$, $p<.01$, $d=1.09$) which were more complete and runnable than those created by Single students. Achievement level did not affect this measure as a covariate ($F(1,27)=.41$, $p=.53$). Correlational analyses was conducted to further reveal if learning outcomes were associated with instances of regulative activities. However no significant correlations were found.

5. Discussion

This study sought to examine differences in regulative tool use during inquiry learning by Pairs and Single students. The presence of a peer was expected to increase learning outcomes and decrease regulative scaffold use.

Certainly the presence of a peer impacted learning outcomes in this study. Pairs achieved significantly higher model quality and lab report scores than Singles. This is consistent with the findings of past research which shows that collaboration generally has a positive impact on learning. Pairs achieved higher model quality scores due to their ability to determine relevant variables and link them through relationship specification more appropriately than Singles. Collaboration also appeared to enhance student's ability to give a more detailed account of both their products and processes as their lab reports showed more elaborate descriptions of template elements than Singles.

The impact of collaboration within the learning outcomes of this study is partially independent from prior achievement. Student achievement levels did not impact model quality scores, but did impact the lab report content of the students. Lab reports were a prevalent evaluation method within this class, and one which the students were quite familiar with doing; therefore it makes sense that their class ranks reflected to some degree their ability to write reports. This conclusion does not extend to the construction of models. This form of abstract problem representation was completely new to the students, which may explain why no effect of prior achievement in physics was found on model quality scores.

Results for learning activities do not confirm the hypothesis on regulative tool use and time measures. Pairs and Singles used the PC for approximately the same duration. The same results hold true for specific tool use measures. Students in both conditions used the goal lists, note taking, hints, help, and report template features about the same amount. But although Singles did not use regulative supports significantly more than Pairs, a strong general trend is apparent in the planning and monitoring data which points toward such a difference. The frequency

data show that Singles did view goal lists, notes, self monitoring and reason justification prompts within note taking, help files, and hints more then Pairs, in addition to showing intent to take notes more often. High standard deviations may have prevented achievement of statistical significance however and further research would be necessary draw any firm conclusions. It may also be that differences between Pairs and Singles lie not with frequency of regulative scaffold use, but in how they used it, particularly across sessions (cf., Bera & Liu, 2006). Future research should explore these issues in more detail.

It was assumed that the presence of a peer might contribute to lower use of regulative scaffolds as collaboration might "supplant" such support. Within this study however collaboration wasn't shown to have any effect on regulative scaffold use which remained fairly low for both Pairs and Singles. Students took only about 2 notes per session, mostly ignored cues, and responded to about half of the possible note prompts designed for comprehension monitoring, and even less so to the prompts designed to help students provide evidence for their understanding. Post-hoc analysis of student use of regulative scaffolds across the four experimental sessions revealed that use of the PC consistently decreased across the four sessions for both conditions ($F(3,26)=18.52$, $p<.01$) suggesting that they still do not see a need to use the tool for monitoring, but more for orienting and planning the task. This is consistent with prior research (Manlove et al., 2006, in press) which showed that use of regulative scaffolds decreases over time, and that the PC was used mainly for planning and little used for monitoring or evaluative activities.

Both this and past research (Manlove et al., in press, see chapter 5) examined how cues and prompts might assist students in using regulative supports for better and more sustained monitoring and evaluation. However results show that cues to promote reflective note-taking for monitoring their work were little used and ineffective when presented as optional timed "pop-ups" to students. The self-monitoring and reason justification prompts within the note forms also showed little use, and decreased across the four sessions. This suggests that students do not see the value of answering prompts as they move into activity conduction. Despite this, past research indicates a favorable impact on learning outcomes by prompting students to elaborate and explain (Davis, 2000, 2003; Ge & Land, 2003; Lin & Lehman, 1999) especially if students are not given the option of ignoring them.

Forced monitoring points within inquiry learning may be a solution to increase regulatory support use and thus regulatory activity of students during technology-enhanced inquiry learning. This might include "freezing" the environment until a note or report of progress is made. However this approach warrants caution, in that forcing students to use a learning strategy such as note taking, prior to their readiness to do so, may be seen as an extra cognitive burden by the students, particularly in

complex learning tasks such as modeling (Lan, 2005). Lan posits that designs might take into account self-monitoring strategies students are already familiar with to offset the cognitive burden imposed by "forced" or unfamiliar regulative strategy supports. Direct instruction of the use of regulatory supports might also reduce the "cognitive competition" students feel between self-monitoring activities and conduction of learning. It may be that student use of regulative supports increases if they understand how, why, and when, regulatory supports benefit their learning with technology enhanced inquiry environments.

Alternatively the implications of this research point to the idea that students may find a separate tool for regulation, such as the PC, as being situated too "far away" from actual activity conduction, which in turn contributes to the cognitive competition described above. Embedding regulation support within tools students use during learning activity work might be a more effective means of supporting regulatory skills throughout the learning experience. Regulative supports designed in this manner might give students the opportunity to situate new goals and notes with a constructed artifact such as a graph, data table, model, or within a simulation setup, quickly and without too much interruption of task conduction. In this way perhaps regulative scaffolds would see more and consistent use over the course of an activity, and serve to strengthen learning and understanding within technology-enhanced inquiry and modeling environments.

7. Synthesizing the research

Abstract

In this chapter, the overall results of the studies found in this dissertation are discussed. First a general introduction is given which revisits the research question driving this research. The second section examines results for each of the regulative support designs from the perspective of the regulative activities. The third section discusses how well regulative supports assisted the learning outcomes found in these works. The fourth section discusses issues which resulted from these studies about learning conditions such as students' prior experience and achievement, and collaboration. Finally the fifth section examines issues related to the future of regulative support design and classroom implementation.

"He spoke to her of Miranda, and of the book, and of the old stories of the deeds of Princess Nell, which he had watched from the wings, as it were, by looking in on Miranda's feed many years ago at the Parnass" (Stephenson, 1995, p. 448).

1. Introduction

Synthesizing research takes a look across studies to identify commonalities and patterns. As such this chapter seeks to describe general conclusions, from the wings, as it were, by looking back over the regulative activities and learning outcomes discussed to give insights about regulative scaffold design within technology-enhanced learning environments. Guiding this synthesis is the general research question which began the iterative cycle of inquiry depicted in this dissertation:

What is the effect of regulative scaffolds on learning activities and outcomes during technology-enhanced inquiry learning with simulations and modeling?

Effectual evidence with regard to regulative scaffolds was seen in two main forms throughout these works: regulative activities and learning outcomes. Regulative activities were operationalized within specific use of the Process Coordinator (hereafter PC). Two studies also included student chat data as evidence of regulative behavior. Student learning outcomes were operationalized as student lab reports and model quality scores. This evidence is synthesized and evaluated in the first two sections of this chapter. Next section 4 discusses condition issues which impacted the investigations, but were not the main point of study. These include; learning task complexity and time, student achievement levels, and collaboration. This chapter ends with a general discussion of how conclusions can inform the future of regulative support and the extent to which cognitive tools of this sort can engage a student meaningfully, in the tasks which technology-enhanced scientific learning environments afford.

2. Regulative activities

2.1. Planning

To return to a comment from a participant's chat found in chapter 1: "What in heaven's name must we do?" To answer this plea for a plan, the empirical studies depicted in chapters 4 through 6 supported students in providing a plan over the course of the entire inquiry. Experimentally, planning was supported within all of these works with goal lists presented in a hierarchical structure. The inquiry learning processes were represented as over-arching process goals, (in a tree format within the studies found in chapters 3 and 4, and then in the form of a visual inquiry cycle in chapters 5 and 6.) These process goals were then broken down

into sub-goals, in keeping with the view that successful self-regulators develop sub-goals to break a task down into less distal components (Zimmerman, 2000).

Overwhelmingly the PC+ was effective in promoting goal viewing, it was in fact the most used feature of the PC+. Students supplied with goal hierarchies in the comparative PC+, PC- works (chapters 4 and 5) viewed these plans more than their non-supported counter-parts. PC- groups, who had the option of setting their own goals, did so sparingly; as such they had relatively little to view. The presence of a peer did not impact goal viewing as evidenced within the results found in the study depicted in chapter 6. Pairs and Singles viewed goals in equal amounts, although a strong general trend was apparent that Singles did use the goal lists more than Pairs.

Less clear from these works is the impact goal viewing had on learning outcomes. The expectation that planning support would positively impact learning outcomes was only borne out partially. Lab report measures were only available within the studies depicted in chapters 5 and 6. Within chapter 5, goal viewing correlated significantly and positively with students' lab reports. This result was not stable however, and was not found within chapter 6's collaborative and individual study. In contrast, conclusions with regard to planning activities' impact on model quality scores are tenuous. A consistent negative direction was found in all the empirical chapters in correlational analysis between goal viewing and the model quality results of students. Meaning the more students conducted these activities the lower their model quality scores seemed to be. Although only one of these negative correlations was significant (see chapter 5), the direction of effects across all studies can't be ignored. Thus a tenuous trend seems to be apparent in which planning activities assisted students with lab report writing, but seemed to have a negative impact on model work.

The form of planning support may be the reason why. Goal-lists can be described as a form of process management support (Quintana et al., 2004). In one sense their primary purpose is to provide support which helps students manage their lack of strategic knowledge about how to select activities and coordinate their efforts. Therefore, a more process-oriented activity such as lab report writing which involves pulling together many aspects of a scientific investigation (i.e., hypothesis with data analysis to draw conclusions), may well benefit from goal lists which give process support. In addition, the lab report template sections were in many cases a one- to-one match with the processes of inquiry listed in the PC+, this could further explain why the goal lists enhanced student reports. Although caution needs to be taken with this conclusion, an alternative explanation is that the PC+ is goal-driven. That is, students had to select a goal to view and copy notes to their reports. In contrast the goal lists may have lacked a certain amount of specificity with regard to

helping students structure their model work. This is despite the inclusion of modeling strategies (i.e., work on the structure of your model before specifying variables) and references to help files about modeling within the goal-appended PC hints (see section 2.2.).

Seemingly more appropriate to model work, were the domain based help files, as evidenced by the results found in chapter 5. The help files contained information about system dynamics variable types and relationships, as well as model editor procedural information. This type of support may have been more helpful to the novice model builders (as all study participants were) due to the specificity of the information. In contrast the focus of the PC+ goal and sub-goal content was on general scientific inquiry cycle processes; as such sub-goals most often represented general strategies. To illustrate, the hypothesis phase of the inquiry learning processes was adapted in Co-Lab to reflect "modeling and hypothesizing". The sub-goals within this phase were; draw a model, specify variables, specify qualitative relationships, and check your model. Together this "general" strategy may not have gone far enough in assisting students in the more specific strategic knowledge needed for model work, as was found in the help files. Thus, the help files possibly allowed students to "fill in" and supplement the general strategy given for modeling in the PC+.

This conclusion naturally is particularly sensitive to the level of student experience. Consistent with the work of Kirschner, Sweller, and Clark, (2006) which points the idea that levels of domain knowledge impact the need and use of support. As students gain experience in modeling, general strategies may be useful in that students can forgo more specified support in favor of internal mechanisms for regulation developed through prior activity and learning. At a novice level however domain information is a key factor for application of an overall strategy such as found in the PC+ for modeling. In other words they may simply lack the experience to "fill in" a general strategy and efficiently regulate its application. Future research with regard to the design of goal lists needs to address the balance between being specific and general with regard to expected learning outcomes, as well as highlighting the link between domain knowledge and general strategy support.

Future research should also investigate the effect of goal-restrictive designs such as found in the PC+. In order to access other regulative features of the PC, students first had to select a goal. This choice restriction was made to scaffold students in the "ideal" behavior expounded in self-regulation frameworks with regard to making choices in a goal-directed manner. PC- students in contrast did not have to select a goal to make a note, but little can be said about whether this was more amenable or useful to students as PC- students showed consistently little goal-setting or goal-viewing activity. Further research could be undertaken which addresses whether this goal-directed restriction

promotes more or better regulative behavior than non-goal restricted use of other regulative features such as hints and notes.

2.2. Monitoring

In contrast to planning, monitoring activity proved much more difficult to support. Monitoring within these works focused primarily on promotion of student note-taking (chapter 4), and eventually on cues and prompts to note-take (chapters 5 and 6). Monitoring was also supported within the PC with the provision of hints, the ability to check off goals, and to view a history of notes over time.

A consistent pattern found in all of the empirical chapters was the relatively low amount of monitoring when compared to PC use for planning. In fact, none of the experimental studies in chapters 4 through 6 found any significant differences between experimental and control conditions with regard to use of the PC to check their understanding and progress. The study in chapter 4 proves that just the provision of monitoring facilities within a regulative tool does not mean students will use them. These results also indicated that students tended to abandon the PC after an understanding of the task was achieved. These facts may illustrate the reluctance students feel about keeping track of what they have to do, at the same time as trying to do a learning activity. Of particular focus in the successive studies found in chapters 5 and 6 then was the promotion of increased and sustained monitoring.

This was done first with the provision of cues to encourage students to take notes, as found in the studies found in chapters 5 and 6. The cues also had little effect, and were more likely to be clicked away by the students then engaged for note-taking or other monitoring activities. These studies also included the addition of question prompts within note-templates to help students check their comprehension and justify their answers. The effectiveness of these prompts can only be tentatively concluded. In chapter 5 where PC+ students only averaged 3 notes over the course of their inquiry (the PC- groups averaged 2) prompt evidence was too scant to glean any informative insights. Within chapter 6 however, where both Pairs and Singles had on average 9 saved notes, comprehension monitoring prompts were responded to the most, with no differences between Pair and Single utilization of this feature.

Monitoring was also supported with goal-appended hints in the studies depicted in chapters 5 and 6-although a caveat to this is that hints were considered a planning activity within the study depicted in chapter 4. This theoretical shift of placement occurred due to changes in the content of the hints. In the study within chapter 4, the hints contained directions about “planning to monitor” that is, to take notes for keeping track of their experiments and modeling insights. Their low use within this study and the decision to include cues and prompts to take over these functions

slightly changed the content of hints as to provide for more detailed strategies when students sought help: a monitoring function. Regardless of this derivative of the self-regulation framework shifts chapter 5 and 6 results indicate hints were also little used and were only the third most frequently conducted regulative activity after goal-setting and note-taking for groups supplied with a fully specified PC.

Just as with planning activities, the expectation of a positive impact of these activities on learning outcomes is only partially supported. Taking notes and viewing them as well as looking at hints showed a consistent negative correlational effect to model quality, but positively correlated with lab report writing (as discussed in section 2.3 below). This can be explained by the fact that notes could be cut and pasted within reports and in fact that the PC+ housed explicit directions to use them as such. The consistent positive correlation with domain based help files and model quality scores also indicates that goal-appended hints did not go far enough in elaborating specific strategies for model work or that the lack of student experience with modeling interfered with their use.

Overall then, regulative supports for monitoring within these studies were ineffective in terms of prompting frequent and consistent student checks of comprehension and progress. Or they failed to capture how students do this within Co-Lab's environment. Two insights fall from the patterns found from the monitoring data: (1) The assumption that students need to evidence increased and sustained monitoring (as was done with goal-viewing) across their inquiry is in question. Originally there was a tacit implication that the frequency and consistency of monitoring with the PC+ should be more in line with the PC+ planning activities. This may not be a valid assumption. (2) From a design perspective; monitoring support designs such as those utilized are too "distant" from activity conduction. This means that facilities for monitoring student work may be more effective if embedded within the transformative activities, rather than in a regulative tool set apart from student work.

Returning to chapter 1, self-regulation has a period of execution, during which students monitor their progress on goals. However attention on the part of the student during learning within a technology-enhanced environment like Co-Lab is also taken up by how to navigate in the environment, collaborate with a partner, and deal with complex science topics and modeling. Having them stop, and externalize their thoughts frequently or equal to goal-viewing, in the form of notes may be too much to expect, and be seen as too interruptive over the course of an inquiry. Despite this, students have been shown to benefit from such interruptions. Self-explanation research cites the advantages of having students externalize their thoughts as a means to promote learning gains (Chi et al., 1994; Kramarski & Gutman, 2006; Renkl, 1997). The question remains then how much externalization of monitoring, i.e., in the form of notes, or discussion, can be expected in these settings? And how much is

productive enough to assist students, while not interfering with their engagement in learning the science topics which is their primary purpose within technology-enhanced environments like Co-Lab?

One way to investigate this question is to examine further how monitoring support can be designed within activity conduction. In Co-Lab students needed to use the PC, a separate tool, to externalize their thoughts. Students also had to select the appropriate goal prior to writing a note. It would be interesting to see if a provision for note-taking was embedded within the transformative tools like the model editor and simulation, would evidence more productive note-taking. For example students could append a note or comment within their models or data-sets. Alternatively obligatory note-taking could be instituted at key points during a session such as at the beginning, middle, and end or, only at the beginning and end. This might leave a majority of session time for activity conduction. Finally another idea is to make student notes a requirement of the activity. Within the activity conducted for the studies found in chapters 5 and 6, students were encouraged to make notes for their lab reports. Instead students simply wrote their lab reports during the last session mostly without the use of their notes. Making student notes a requirement, i.e. something they need to turn in for teacher assessment, might also make students attend to this feature.

2.3. Evaluation

Students had the opportunity to take a step back from their inquiry work and evaluate both their artifacts and working methods with lab reports in the studies found in chapters 5 and 6. Within the study depicted in chapter 5, only PC+ students had access to this template, whereas it was available to both Pairs and Singles in the study in chapter 6. The support mechanism in place was a template which listed sections to include, as well as a description for each which encouraged reflection on quality and explanations for their ideas. For example, in the conclusion section of their reports students were asked to explain why (or why not) their models were accurate in prediction of outflow rates. They were also asked to explain what they would do differently to improve their inquiry outcomes.

PC+ students did evidence both significantly better structured lab reports and included significantly more content than PC- dyads (see chapter 5). PC- dyads in contrast had lab reports which were less well-structured and usually only emphasized one experiment with the water tank simulation or only addressed their model work at a shallow level, as evidenced by, statements such as “we couldn’t get it to work” with an explanation as to why. Whereas PC+ dyads’ reports elaborated on both experiments and their models and tried to bring the two together by viewing their work from the perspective of their research questions (as highlighted in the introduction section of the lab report template). In other words the less

supported students, forced to rely on their own knowledge of what to include in lab reports from their science class experiences, created a less coherent view of their inquiry work and conclusions.

Within the study depicted in chapter 6, Pairs evidenced better structured lab reports which included more elaboration of content than their Single counter-parts. This indicates the benefits of collaborative work for evaluation: presence of a peer may assist student discussions of the template sections which leads to more elaboration and better structure. In this sense, it is assumed that the template provided Pairs with points to discuss and describe which possibly lead to more detail within their lab reports. Future research however should investigate the role student conversations play while using regulative supports like templates as the works depicted did not investigate this aspect at a detailed level.

Both of these outcomes indicate that lab report templates show promise as a means of supporting evaluation of scientific inquiry work, particularly if written collaboratively. However caution remains with regard to this result. Evaluation of the template was based solely on the structure of the students' lab reports and elaboration of content. Elaboration was based on inclusion of points found in the template, and not necessarily on the quality of physics knowledge gained (which was assessed from students' final model quality scores). Future research should look into more detail with regard to the quality of students' learning of specific physics topics within these reports, perhaps examining lab reports in conjunction with standard knowledge tests to see if templates assist with declarative knowledge gains and transfer of knowledge to related science problems.

3. Learning outcomes

Whereas the preceding sections addressed specific regulative support activity and it is relation to the two learning outcomes found in these studies (namely model quality and lab report content and structure), this section takes a comprehensive view of the supports and their relation to learning outcomes.

In two of the studies, the model quality scores of the experimental groups met expectations. In chapter 4, PC+ students evidenced significantly higher model quality scores than PC- students, and in chapter 6, collaborative groups also had better models than Single students. Within the study depicted in chapter 5, PC- students evidenced significantly better model quality than their supported counterparts. What happened then between the study depicted in chapter 5 and the one in chapter 4? In chapter 5, PC+ students had the additional support of cues and note template prompts as well as a lab report template to handle. This perhaps "over abundance" of support may have lead students to feel torn between

understanding their modeling work and regulation of their inquiry-a fact supported by the negative correlations between regulative support use and model quality scores. Help files seemed to be more beneficial, perhaps simply because they contained information about system dynamics variable types and relationships. Not finding the general strategy illustrated within the goal lists for modeling useful students sought help elsewhere, effectively ignoring the more detailed modeling hints appended to the goals.

Future regulative support for student construction of models then, particularly for novice students, might entail a more directed approach. Within the studies depicted here, students were given a modeling introduction. This introduction covered the operation of the model editor within Co-Lab and the basics of system dynamics modeling, such as types of variables and relationships. This introduction was conducted within a non-science domain, namely finance. Future research should investigate whether a modeling introduction which deals with a science domain might be more easily transferable to experimental tasks in science learning with technology-enhanced environments. In addition novices may benefit from directed support with practice modeling prior to its use within an overall inquiry. In this way students could be supported to learning how models work prior to trying to use them for knowledge expression within an overarching scientific inquiry task. This may change the outcomes for the use of the regulative scaffolds. It also points to the fact that more detailed research needs to be conducted with regard to how students can be supported to regulate their model building, particularly if they are novices.

Results found for lab report scores of the experimental groups were as expected in the studies found in chapters 5 and 6. The regulative supports overwhelmingly assisted students in creating more elaborate and well structured reports of their inquiry. This was explained above within the regulative activities section as being a factor of the process type support the PC supplied. Lab reports being a more process-oriented measure did benefit from the regulative activities of the students, as seen in the correlational analysis between goal viewing, note-taking and note-viewing which showed significance in chapter 5. As such a general conclusion with regard to the PC+ performance overall is that is it is useful to provide students with a process support, especially if process measures are used.

In contrast the effects of regulative scaffolds on model quality were unexpected and highlight the difficulty of providing strategic knowledge to novices without domain knowledge. These effects nicely illustrate the learning paradox: that students need to interact meaningfully to learn, but in order to do that they need to already possess the requisite strategies and domain knowledge. Future inquiry work which includes modeling as an expressive mechanism of knowledge needs to be very careful that students do not feel torn between understanding the science content, and

understanding modeling formalisms. Although this was not investigated specifically within these works, student level of experience with modeling, as evidenced by the reliance on domain based help files, indicates the plausibility of this conclusion. As such future research needs to determine the plans and standards students attend to while building a model so regulative support can specifically, rather than generally assist students in regulation of this type of work.

4. Learning conditions

Many factors influence learning. Results of the research conducted within this dissertation point to two important factors to take into account when designing regulative support. The first is student's prior experience and knowledge and the second is task complexity and time. With the exception of the study depicted in chapter 6, students had no prior experience with the domain of fluid dynamics. Within chapter 6 students had been exposed to this domain, albeit in one introductory unit. In addition, none of the student participants had any experience building system dynamics models.

How did prior experience impact the use of the regulative supports within the studies found in this dissertation? All of these students, being in the last years of high-school science had experience with conducting and reporting lab experiments. From this perspective the process support supplied to them within the PC+, being of a general nature was familiar to them. They could be considered to know the overall steps to take in using the scientific method, maybe not specifically or with a degree of quality, but generally. The process support found within the PC then may have been useful simply because it served to remind students to stop and take a look at the goals they were striving for in a manner they recognized; they had experience with it in other words. The process could be easily integrated with prior knowledge of what they understood to be the scientific method of inquiry. Contrasted with modeling however, where students had no experience, the usefulness of the regulative supports designed for the studies in this dissertation is more in question.

The above description points toward the link between prior experience and use of regulative scaffolds, and naturally the behavior of regulative skills such as planning, monitoring and evaluation. Theories on self-regulation hold that students continually engage in a cyclical process of goal attainment for learning. From their learning environments they glean an understanding of the tasks and standards against which to judge progress and quality. At the same time, they also bring their own background knowledge in and search for strategies which might be applicable to the new learning situation. In absence of prior experience, strategies and content knowledge, technology-enhanced learning

environment and regulative scaffold designs may need to afford increased opportunities for learners to rehearse and practice requisite skills prior to their implementation in a formal inquiry setting.

Naturally, students' prior achievement in science is also a factor in the use of regulative support. This is nicely illustrated within chapter 5 where low-achieving dyads in the PC- condition were shown to have created better models than their supported counterparts. This was explained within this study as a factor of their reliance on domain based help files. PC+ low achieving dyads in contrast may have been overburdened with trying to understand the regulative directions found in the goals, hints and lab template. Not to mention navigating the cues to note take and comprehension checking and reason justification questions found in the note templates. Thus achievement levels of students will also impact the usefulness and effect of regulative supports. To counter this, regulative support which explicitly helps students with acquisition and memory of domain knowledge first and secondarily with its application may be more useful.

Both of the above points with regard to student prior experience and achievement in science are impacted by learning task complexity and time. Within chapter 1, modeling was described as being a design problem (Jonassen, 2000), which is considered ill-structured and therefore more complex than might be a text book physics problem about fluid dynamics. The complexity of this task and its unfamiliarity may have impeded the effects of the regulative scaffolds, despite efforts. Students were supplied with an introduction to modeling, and were given specific modeling strategies within goal-appended hints. In addition they were supplied with help files for model domain information. Despite these supports, the lack of regulative scaffold use for monitoring suggests students did feel burdened by trying to regulate and trying to understand domain content.

Future research might study the effect of simplifying modeling tasks via model progression. Model progression for novices starts with inquiry investigations of a simplified version of the model and then progresses to inquiry tasks incorporating increased complexity (Swaak et al., 1998). For example; a partial models could be offered that students work to complete in a first stage of model progression. Then as experience is gained, students work towards construction of an entire model from scratch. This might serve to reduce the complexity and allow students the room to regulate their understanding as they go. Future research also needs to investigate whether simply more time was needed with this sort of task. Students within the studies found in this dissertation were first supplied with two hours and then four to complete the task. While the time increase did allow for more complete model construction and lab report writing, it may still not have been enough for students to feel they had time to take advantage of the comprehension monitoring supports found in note templates.

Collaboration also played a role within this research. The presence of peers was incorporated due to research which implies its usefulness in promotion of regulation (Brown *et al.,* 1983; Lazonder, 2005; Osman & Hannafin, 1994). One main issue with regard to collaboration and regulative supports deserves notice from the works depicted in this dissertation: that if collaboration promotes regulation, what is the role of the regulative support? As shown in the study depicted in chapter 4, a substantial negative correlation was found between regulation of the learning task (RLT) talk and viewing goal descriptions in the PC+ group. This evidence highlights the dangers of providing support which overlaps another supportive mechanism, like the presence of a peer. The research depicted in chapter 6, despite showing that Singles and Pairs use regulative supports about the same also indicates a general trend for higher Single use. Although no firm conclusions can be drawn from either of these pieces of evidence, the question does remain how to optimize regulative support in collaborative learning settings, especially since two heads may regulate better than one already; thus what is the added value of regulative support?

A possible short answer to this question may be found in the use of the goal lists and report template. In the study depicted in chapter 6, Pairs produced more elaborate reports but used the report template as often as Singles did. The report template may have provided "talking points" for groups from which to elaborate their knowledge. In this sense it may have focused the Pairs' discussions. The same may hold true for the use of goal lists, they provided an initial point from which students could elaborate together for the finer points of regulation found in monitoring acts. The fact that the question prompts within note-templates which strove to get at these finer points weren't used as often also point to the idea that partner discussions may be seen as more efficient to students than notes, particularly in complex tasks where students do not feel they have time to complete the task. Future research with regard to regulative support designed for collaborative use needs to investigate further how process supports might work in tandem with student discussions to promote and externalize monitoring acts.

5. The future of regulative support

If anything the results found across these studies indicate that process support, while helpful to the evaluative work done in lab report writing, does not extend to providing *in process* evidence of monitoring. But what do these series of studies say about the future of regulative support and whether the designs utilized meet the call for "meaningful engagement" with inquiry tasks?

Meaningful engagement with an inquiry task within the studies depicted in this dissertation translated into regulative activities such as planning, monitoring, and evaluation as operationalized by PC use and the knowledge expressed in their models and lab reports. As already stated, results are mixed and were perhaps confounded by the complexity of asking students to construct system dynamics models while trying to regulate and understand an abstract physics topic.

One answer to this dilemma may be in adaptable scaffold design. That is, scaffolding that is adaptable within a particular system to suit the needs of the learner (Jackson, 1996; Soloway, Guzdial, & Hay, 1994). This naturally has the advantage of meeting the more individualized needs of students as they work within a technology-enhanced learning environment. To illustrate, the novice model building participants found in the studies depicted in this dissertation might utilize regulative support which focused initially on their planning, monitoring and evaluation of modeling concepts. Later once students felt this understanding was reached, regulative support aimed specifically at the level of inquiry might take center stage to help them implement a model within a scientific investigation. Although promising, this approach to the design of scaffolds also comes with complex questions about who determines the support to be supplied, and at what time? How will the system know when different scaffolding mechanisms are needed? White, Shimoda, and Frederiksen (2000) discuss how students can play a role in adapting scaffolding support as needed which shows promise but also the danger that students can actually articulate those needs.

Another aspect of regulative support design is the issue of "grain size" and how to measure it. Within the studies depicted within this dissertation monitoring activity was defined primarily as note-taking. Note-taking could be considered a rather large action, where students try to explain or jot down their ideas so they become objects of monitoring for comprehension. However, many other monitoring activities may have been conducted by students within the transformative tools. Actions that were at a much smaller grain size and as such were left un-captured within the analysis depicted in the studies of this dissertation. When students change the variables in a simulation after reading a graph for example, what triggered them to do so? And could this be called a monitoring act? The future of regulative support design needs to examine how small cue-response activities (Butler & Winne, 1995) within technology-enhanced learning environments might be captured and capitalized on to inform design decisions (Nesbit et al., 2006).

The future of regulative support design also needs to take into account another important person in the process of implementation: the teacher. As stated in chapter 1, the teacher often takes a regulative function for students, asking thought-provoking questions, setting goals, and helping students see their mistakes. Although not an aspect of study within the

works depicted here, the role of the teacher cannot be ignored within educational research and within implementation issues for technology-enhanced learning environments. As such regulative support within technology-enhanced learning environments needs to investigate how it can best supplement this role towards helping students make meaning of their scientific inquiry investigations. Issues about the value added for regulation support when a teacher (or peer) is present need to be identified and addressed within designs.

In conclusion, the promise of technology-enhanced learning environments is extraordinary. Students can visualize and manipulate data and information to create meaning in situations where it would otherwise be impossible for them to do so. The explosion of research with regard to how to best support students to integrate understanding with prior knowledge structures runs the gamut from environment directive support to open-ended unguided student control, all with their own set of advantages and disadvantages. Affordance of student ability to regulate their cognition during learning is often at the heart of these supports, allowing them to effectively set goals and monitor their attainment for learning, make adjustments when needed, and step back to evaluate their progress for future action. This metacognitive ability propels learning, allowing students to learn throughout their lives, often despite environmental circumstance. In short, regulatory skill helps students "to the discovery and perception of the truth that 'they themselves are makers of themselves'" (Allen, 1902, p. ix).

English summary

Introduction

This dissertation is about supporting students to regulate their science learning within a technology-enhanced learning environment. Regulation involves making plans, monitoring progress and understanding, and taking a step back at key moments to evaluate both learning products and processes. These skills are thought to enhance learning gains for students. During classroom settings teachers often take a regulative function to promote enactment of these skills. Thought-provoking statements and questions help students make goals for learning, check their comprehension, and help them evaluate final products and work processes. As such, teachers provide a "natural" scaffold for regulative skill enactment. Within technology-enhanced settings supporting regulative skill is less clearly defined. Therefore the general research question guiding the studies depicted in this dissertation is:

What is the effect of regulative scaffolds on learning activities and outcomes during technology-enhanced inquiry learning with simulations and modeling?

The regulative scaffolds were implemented within a technology-enhanced learning environment called Co-Lab. This learning environment was designed to afford student use of simulations to discover scientific phenomena and the ability to represent their understanding through system dynamics modeling. Co-Lab's interface tools allowed students to navigate between virtual rooms in a virtual building. The rooms represent inquiry processes, such as orientation (hall), hypothesis generation (theory), experimentation (lab), and drawing conclusions (meeting). Students could also manage aspects of collaboration such as; tool control, location of group members, and discussions via a chat tool. Room-specific tools were also available such as a water tank simulation, a table and graph tool for data analysis purposes, and a model editor which allowed students to construct system dynamics models. A help tool housed html-based documents for the operation of the environment as well as background information related to the domain and modeling.

The experimental tasks students completed for the studies described in the studies found below were conducted within the domain of fluid dynamics. Students were introduced to basic concepts relating to water inflow and outflow via use of the water tank simulation, mentioned above. This simulation allowed students to vary tank, tap, and drain values, as well as, water inflow rates. Student regulative activities and learning outcomes were collected in the four studies. Regulative activities were indicated by students' use of the PC; in study 1 and 2 the students' chat

communication served as an additional data source. Learning outcomes were assessed from student constructed system dynamics models and, in the last two studies, student lab reports.

Study 1: Exploring task approach, collaboration, and regulative patterns

This study examined students' spontaneous, unprompted regulative behavior during a two-hour inquiry session in Co-Lab. Regulation included two basic processes: planning and monitoring. Ultimately the goal of this study was to provide recommendations for the design of Co-Lab and its tools in order to optimize support for regulation in areas where students need it.

Thirty-nine students worked in groups of three, resulting in 13 triads randomly assigned by the experimenter. Due to technical difficulties however, only 7 of the 13 groups could be used in the analysis. Group members collaborated online and communicated via Co-Lab's chat function. Their task was to attain equilibrium in the water-tank. They were told to first use the simulation to discover how factors such as inflow and outflow affected the water level in the tank, and then were asked to develop a system dynamics model of this phenomenon. Domain help files related to water volume, and system dynamics modeling were available to assist students. The PC was set up with five top level goals; (1) before you begin, (2) modeling and hypothesis generation, (3) data collection, (4) drawing conclusions, and (5) evaluation. Students could add their own top level goals, or add sub-goals to the existing ones. They could also append notes to goals and view a history of their notes. The PC was housed only in the meeting room.

Log files revealed navigational data about what rooms students visited, and how they spent their time. This data indicated that students very rarely went to the meeting room, where the PC was housed. Instead they concentrated almost solely on work in the lab and theory rooms with the water tank simulation and the model editor. Analysis of the groups' chat data was performed to reveal whether students regulated their inquiries through communication rather than with the PC. Results showed that students indeed engaged in a high degree of regulative talk overall but most of it pertained to regulation of their collaboration (RC). RC communication included episodes related to finding out which room a group-mate was is, group focusing, and task division. Less apparent in the chat data was communication pertaining to regulation of the learning task (RLT). Two types of episodes were found, planning and monitoring. Planning episodes mostly consisted of an ad-hoc nature: They were short-term goal statements comprising a proposal for immediate action by one

student, followed by confirmation from group-mates. Monitoring episodes contained mostly expressions of comprehension failures.

Overall the results of this study indicate that students do not engage in spontaneous regulation of their work and need assistance with the complex task of model building. The relatively low instances of meeting room visits (where the PC was housed) further suggests that students might not go to a "separate" virtual room in order to use a tool for regulative purposes. Finally, most groups only achieved partial models or model sketches. This indicates that students might benefit from a longer task time, or that the task should be slightly simplified in order to make it more manageable for students to achieve within the time given.

Study 2: Examining regulative scaffolds during inquiry learning

Given the results of the previous study, this experimental work sought to examine two versions of the PC which was housed in every room of Co-Lab, and the inquiry task was altered slightly to make it more amenable for a two hour time period. Groups in the experimental condition received a PC with regulatory guidelines (PC+); control groups were given a version of this tool from which these instructions were removed (PC-). The regulatory guidelines were a hierarchical goal list including large process goals, such as seen in study 1, as well as sub-goals to further elucidate strategies for goal attainment. In addition goals were appended with hints which provided further detailed information and tips. Students could also append notes to their goals, view a history of their notes and cut and paste them into a report editor. This editor was supplied with a template which provided guidelines as to what sections and content to include in their lab reports so as to better evaluate their inquiry efforts.

61 high-school students worked online in Co-Lab in groups of three, at separate computers, and communicated only via the chat tool. 19 triads and two dyads were formed by track ability matching. Random allocation of student groups into the conditions resulted in 10 PC+ and 11 PC- groups. Due to technical issues within Co-Lab and absentee students, incomplete data were retrieved for 3 PC+ and 2 PC- groups.

In terms of learning outcomes, results showed that PC+ students had significantly better models than their PC- counter-parts. Lab reports could not be assessed as two hours proved insufficient for students to complete them in addition to their modeling work. Concerning the regulative activities of the students; PC+ groups viewed the goal lists significantly more than PC- groups. However, use of the PC for monitoring, as encapsulated by student note-taking activity however did not show any differences across conditions. Chat data elucidated how regulative

scaffolds interacted with learning outcomes and regulative activities. This data again showed a comparatively high percentage of regulative communication but no differences in amounts were found between conditions. The proportion of RC and RLT episodes did not differ between conditions either. However, correlational analysis revealed that the more PC- students communicated about regulation of the learning task and about the task itself (cognitive episodes), the higher their model quality scores. This result was not found within the PC+ groups where in fact a substantial negative correlation was found between learning outcomes and RLT communication. Further qualitative analysis revealed that the PC+ reduced the need for RLT communication; PC+ groups could simply follow the goal lists in the PC and their chat files indicated that they initially did so. However once the PC+ groups had attained a global understanding of the task, they focused on task execution and hardly returned to the PC.

To conclude, this study showed facilitative effects for the PC+ on students' models and initial planning. However, the PC+ failed to elicit monitoring activity as expected. Specifically the fact that the PC was used primarily for planning, and then abandoned it after task understanding was reached meant that students might benefit from increased attention to monitoring their understanding through note-taking.

Study 3: Refining regulative scaffolds during inquiry learning

The third study conducted aimed then to promote increased and sustained monitoring via note-taking throughout the inquiry sessions. This was done with the provision of timed cues to suggest taking a note. Two question prompts were also added to goal-appended note templates to further focus students on comprehension monitoring. The first question type elicited explanations for goal comprehension (e.g., "What is your research question and how does it relate to your model and lab report?"); the second type asked students to provide evidence for their answers (e.g., "How does your research question meet the standards your teacher would use to evaluate it?"). In addition, top- level goals were displayed with a visual inquiry cycle rather than in a goal tree format. Students could click a phase in the visual inquiry cycle diagram and see a list of sub-goals related to that phase. All other aspects of the PC remained the same. Regulative guidelines were also supplied within a lab report template which was housed as a help file rather than within the report editor.

In an empirical evaluation, 70 secondary school students (aged 16 to 18) worked in dyads. In contrast to the previous two studies, students collaborated face-to-face in front of one computer. Participants were

allocated into medium-range mixed ability dyads. 20 dyads received a "full" version of the PC (PC+) with the regulative guidelines described above; dyads in the control group (n=15) worked with an "empty" PC which contained minimal structures for regulative support (PC-). PC- students could make their own goals, view them and create notes. Students had twice as much time in this experiment than they had in prior studies. This was due to the fact that in study 2 (despite reducing the complexity of the task) two hours appeared insufficient for students to complete their models and lab reports.

Results showed that both the frequency and duration of regulative tool use differed in favor of the PC+ dyads, who also wrote better lab reports. PC– dyads viewed the content help files more often however and produced significantly better models. In addition analysis showed that the latter effect applied to low-achieving dyads only. This could mean that the regulative directions found in the PC+ are more confusing than helpful to lower-achieving dyads. Results for increased and sustained monitoring were not achieved. This study in particular found very few instances of note-taking with no differences between conditions. The cues to note take were more often clicked away then attended to by the students. Correlational analysis between regulative activities and model quality scores revealed a significant negative relationship between these constructs, meaning that students who engaged in more PC activity (either PC+ or PC-) seemed to have lower model quality scores.

Study 4: Collaborative versus individual use of regulative scaffolds

The low instances of monitoring found in the prior works point to an issue within research on technology-enhanced learning environment scaffold use. That is, they are often little used by students, particularly if they are regulative in function. One reason may be that students often work collaboratively in these settings, and their group work may interfere with the use of regulative supports. This final study sought to compare the use of regulative scaffolds within Co-Lab by Pairs and Single students. Pairs were predicted to make less use of regulative scaffolds than Singles but to have better model quality and lab report scores.

To validate this assumption, 42 high-school students worked either individually (n=18) or in pairs (n=12) within Co-Lab. Students in the Pairs condition were grouped into medium range mixed ability dyads based on teacher supplied class ranks. Pairs worked together face-to-face in front of one computer. Two regulative scaffolds were used to assist both Pairs and Singles with planning, monitoring, and evaluating their investigative efforts: the fully functional PC+ as found in study 3, and the lab report

template. Timed cues for note-taking and note-template prompts were also present.

Results showed that Pairs constructed better models and wrote better lab report compared to Singles. Data for regulative scaffold use showed a consistent and strong trend of increased regulative tool use by individual students. However, the frequency and duration of regulative tool use did not differ significantly between conditions. Covariate analysis of achievement did not reveal any impact on these findings and correlational analysis did not reveal any significant differences between regulative scaffold use and learning outcomes in either condition.

Conclusion

In general the studies reported here show that when left with no support students have difficulty planning and monitoring their own inquiry efforts. They also show that the PC, although effective for planning, was less successful at assisting students to monitor. In addition the final two works show that a lab report template can be helpful in supporting students to evaluate their inquiries.

The lack of effects for monitoring may indicate three ideas. First that monitoring with a tool that is set-apart from task conduction may be seen as too interruptive to students. Monitoring supports might be utilized more if set within materials directly related to the activity. In the case of Co-Lab, a provision to take notes, for example, could be placed within the simulation, graph, table, and the model editor. Secondly, supports for monitoring may be more effective if they are obligatory. In case of note-taking cues, this could be achieved by freezing the environment until students take a note (as opposed to the non-obligatory prompts to take notes found in the studies depicted here). Caution should be taken with this approach due to the danger that it is unproductive to the student and seen as more interruptive rather than useful. Future research needs to determine the proper placement between helping students monitor their understanding and inquiry efforts without interfering (to the student's view) with task conduction. Thirdly, the assumption that students need to evidence increased and sustained monitoring throughout their inquiry *to the same degree* as they engage in planning is in question. This raises the issue of how much externalization of monitoring in the form of notes, or discussion can be expected in these settings. And how much is productive enough to assist students, while not interfering with their engagement in learning the science topics which is their primary purpose within technology-enhanced environments like Co-Lab.

Another finding concerns the match between support form and learning outcomes. Evidence of this comes from two consistent correlational trends apparent across the final three studies. It seems that the more

students used the PC, or communicated about regulation of the task, the lower their model quality scores seemed to be. (Although this result only achieved significance in one study, the consistent negative direction of the correlation was present in all three experimental works.) In contrast, the use of the PC's goal lists positively correlated with lab report scores. The PC, is a process support, as such it may have positively impacted lab reports, the content of which was often a one-to-one match with the phases of inquiry. Thus the goal lists may have reminded and attended students to content for their reports. As it pertains to supporting modeling work, however, the PC may have lacked a degree of specificity when it came to assisting students to plan, monitor, and evaluate their models. Instead the rather "general" strategy given in the PC for modeling may not have gone far enough in assisting students in the more specific strategic knowledge needed for model work, especially for novices. In contrast the use of help files significantly and positively correlated with the model scores of students in study 3. Modeling domain information coupled with technical information about use of the model-editor (as found in the help files) in contrast, possibly allowed students to "fill in" and supplement the general strategy given. These results are tenuous however and future research needs to investigate the nature of a regulative scaffold's relationship to different types of learning outcomes. In particular research needs to examine how students plan, and check their model building, insights from which could inform future regulative support designs for this specialized skill.

Future research on the design of supports which assist students to regulate their learning need to take into account two further issues. First, how to capture the often miniscule acts involved in regulative thoughts. The works depicted here examined taking and saving notes as monitoring acts. However many other monitoring acts may have occurred which remained un-captured in the studies presented in this dissertation (e.g., what students attends to when checking their understanding of a graph). The future of regulative support design needs to examine how such spontaneous regulative activities within simulations, tables and graphs might be captured and capitalized on to inform design decisions Another issue is the role regulative support takes in the presence of a teacher or peer. Another person to assist in regulation is already a powerful support, which begs the question of how regulative scaffold designs can be of added value supplementing teacher and student interactions so as to maximize productive regulation during learning.

Nederlandse samenvatting

Inleiding

Deze dissertatie gaat over het ondersteunen van leerlingen bij het reguleren van hun leerproces in elektronische leeromgevingen voor onderzoekend leren. Regulatie omvat het maken van een planning, het controleren van de voortgang van het leerproces en het begrip van de leerinhoud (monitoring), en het op kritische momenten evalueren van zowel het leerproces als de leeruitkomsten. Deze regulatieve vaardigheden worden algemeen geassocieerd met beter leren. Bij klassikaal onderwijs kunnen docenten hun leerlingen stimuleren om deze vaardigheden te gebruiken door bijvoorbeeld vragen te stellen of aanwijzingen te geven. In die zin bieden docenten een 'natuurlijke' ondersteuning van de regulatie. In elektronische leeromgevingen is het minder duidelijk hoe regulatieve vaardigheden op een effectieve manier kunnen worden ondersteund. De overkoepelende onderzoeksvraag voor de in deze dissertatie beschreven studies was de volgende:

Wat is het effect van regulatieve ondersteuning op leeractiviteiten en leeruitkomsten bij onderzoekend leren in elektronische leeromgevingen met simulaties en modellen?

De regulatieve ondersteuning was geïmplementeerd in Co-Lab, een elektronische leeromgeving voor onderzoekend leren in de exacte vakken. In deze leeromgeving konden leerlingen met behulp van een computersimulatie natuurwetenschappelijke principes ontdekken; de kennis die zij hierdoor ontwikkelden konden zij weergeven in een werkend, door de computer uit te voeren model. In Co-Lab konden de leerlingen navigeren tussen verschillende kamers in een virtueel gebouw. De kamers symboliseerden fasen uit het onderzoekend leerproces: oriënteren (de hal), experimenteren (het lab), modelleren (de theorie kamer) en het trekken van conclusies (de vergaderkamer). In elke kamer waren specifieke onderzoekstools aanwezig zoals een simulatie van een watertank, tabellen en grafieken voor het analyseren van data, en een modelleer tool voor het maken van het model. Daarnaast bevatte de leeromgeving enkele tools ter ondersteuning van de samenwerking; voorbeelden zijn een tool om te zien in welke kamer de overige groepsleden zich bevinden en een chat tool om met elkaar te communiceren. Tot slot werd in de help tool informatie gegeven over het gebruik van de leeromgeving, alsmede achtergrondinformatie over het domein en het maken van modellen.

Met deze leeromgeving zijn vier studies uitgevoerd waarin de invloed van regulatieve ondersteuning op leeractiviteiten en leeruitkomsten is

onderzocht. Bij leeractiviteiten is hoofdzakelijk gekeken naar de regulatieve aspecten van het leerproces. Deze aspecten zijn gemeten aan de hand van het gebruik van de tool voor regulatieve ondersteuning: de Proces Coördinator (PC). In studie 1 en 2 zijn de chat files van de leerlingen als extra gegevensbron voor regulatieve leeractiviteiten gebruikt. Leeruitkomsten zijn bepaald aan de hand van de door leerlingen gemaakte modellen; in studie 3 en 4 is bovendien gekeken naar hun eindverslagen.

Studie 1: Een verkennend onderzoek naar de werkwijze, samenwerking en regulatie tijdens onderzoekend leren

In deze studie is onderzocht welke regulatieve leeractiviteiten leerlingen 'spontaan' uitvoeren tijdens een twee uur durende sessie in Co-Lab. Twee regulatieve activiteiten stonden hierbij centraal: planning en monitoring. Het uiteindelijke doel van deze studie was om de Co-Lab leeromgeving en tools verder te verbeteren en met name de regulatieve ondersteuning zo goed mogelijk af te stemmen op de behoeften van de leerlingen.

Negenendertig leerlingen uit 4 VWO werden *at random* ingedeeld in groepen van drie, wat resulteerde in 13 drietallen. Door technische problemen konden echter slechts 7 van de 13 groepen geanalyseerd worden. Groepsleden werkten online samen en communiceerden via de chat. Hun taak was een dynamisch evenwicht in de watertank tot stand te brengen. De leerlingen werden geïnstrueerd om eerst de simulatie te gebruiken om te ontdekken hoe factoren zoals instroom en uitstroom van invloed waren op het waterpeil in de tank, en daarna deze inzichten in een model weer te geven. Hierbij konden de leerlingen achtergrondinformatie raadplegen over vloeistofdynamica en het maken van een model. De PC was alleen beschikbaar in de vergaderkamer en bevatte vijf doelen: (1) voor je begint, (2) modeleren en het genereren van hypotheses, (3) het verzamelen van gegevens, (4) conclusies trekken en (5) evaluatie. De leerlingen konden hun eigen doelen aan deze lijst toevoegen, of subdoelen opstellen onder een van de gegeven doelen. Bij elk (sub)doel konden aantekeningen worden gemaakt, die achteraf konden worden bekeken.

Uit analyse van de logfiles bleek hoe de leerlingen tussen de verschillende kamers navigeerden en hoe ze hun tijd in elk van deze ruimtes besteedden. De resultaten lieten zien dat de groepen zich vrijwel uitsluitend concentreerden op werk in het lab (experimenteren) en de theorie kamer (modelleren). De vergaderkamer werd zeer weinig bezocht waardoor de PC nauwelijks werd gebruikt als hulpmiddel voor de regulatie van het leerproces. Regulatie bleek voornamelijk te gebeuren door te communiceren via de chat, wat bleek uit het relatief hoge percentage regulatieve chat-berichten. Het merendeel van deze berichten

had betrekking op de regulatie van de samenwerking (RS). Deze berichten konden worden geclusterd in episodes die verband hielden met het lokaliseren van groepsleden in andere kamers, het richten van de aandacht van de groep, en het verdelen van taken. Berichten waarin het leerproces werd gereguleerd (RLP) kwamen naar verhouding minder vaak voor. RLP berichten werden verder geclassificeerd als planning episodes en monitoring episodes. Planning episodes bevatte voornamelijk korte-termijn doelen bestaande uit een voorstel voor de eerstvolgende actie door een groepslid, gevolgd door een bevestiging van de overige groepsleden. Monitoring episodes bestonden meestal uit uitingen van onbegrip.

Over het geheel genomen blijkt dat leerlingen slecht in staat zijn hun leerproces te reguleren. Het infrequente bezoek van de vergaderkamer (waar de PC zich bevond) suggereert verder dat leerlingen niet geneigd zijn naar een andere virtuele ruimte te gaan om hun leerproces te reguleren. Verder bleek dat de meeste groepen slechts een zeer voorlopig model hadden weten te construeren. Dit wijst er op dat leerlingen meer tijd en ondersteuning nodig hebben om deze taak uit te voeren. Op basis van deze resultaten is de leeromgeving voor de studies 2, 3 en 4 op enkele punten aangepast. Zo konden leerlingen de PC vanuit elke kamer raadplegen en werd de leertaak ingeperkt door leerlingen alleen de uitstroom uit de watertank te laten onderzoeken en modelleren.

Studie 2:Regulatieve ondersteuning bij onderzoekend leren

In dit experiment zijn twee versies van de PC met elkaar vergeleken. De groepen in de experimentele conditie kregen een PC met regulatieve ondersteuning (PC+); de controle groepen kregen een versie van deze tool zonder ondersteuning (PC-). De regulatieve ondersteuning voor planning bestond uit een hiërarchische lijst met doelen, zoals gebruikt in studie 1, aangevuld met subdoelen om strategieën voor het bereiken van de doelen verder te verhelderen. Aan deze doelen waren bovendien suggesties toegevoegd met tips en gedetailleerde informatie. Monitoring werd ondersteund door leerlingen de mogelijkheid te geven aantekeningen te maken bij de doelen. Leerlingen konden hun eigen aantekeningen bekijken en kopiëren naar een eenvoudige tekstverwerker waarmee een eindverslag kon worden geschreven. Deze tekstverwerker bevatte een sjabloon met richtlijnen voor de opbouw en inhoud van een eindverslag die waren bedoeld om het evalueren van het leerproces en de leeruitkomsten te ondersteunen.

Het onderzoek is uitgevoerd met 61 leerlingen uit 5 VWO. De leerlingen werden in kleine groepjes ingedeeld op basis van hun profiel (vakkenpakket). Dit resulteerde in 19 drietallen en 2 tweetallen, die willekeurig werden verdeeld over de PC+ conditie (n=10) en PC- conditie

(*n*=11). Tijdens het onderzoek werkten de groepsleden achter hun eigen computer en communiceerden met elkaar via de chat.

Vanwege technische problemen met Co-Lab en afwezigheid van leerlingen waren de data van drie PC+ en twee PC- groepen incompleet. Uit analyse van de beschikbare data bleek dat de PC+ groepen significant betere modellen hadden gemaakt dan de groepen uit de PC- conditie. (De eindverslagen konden niet worden geanalyseerd omdat twee uur te kort bleek om zowel een model als een eindverslag te maken.) Wat betreft de regulatieve activiteiten bleek dat de PC+ groepen de PC significant vaker gebruikten voor planning dan de PC- groepen.

Het gebruik van de PC voor monitoring was in beide condities gelijk. Analyse van de chat communicatie liet wederom een relatief hoog percentage regulatieve berichten zien, maar ook hier werd geen verschil tussen de condities gevonden. De verhoudingen van RS en RLP episodes verschilden evenmin. Voor PC- groepen werd echter een positieve correlatie gevonden tussen de hoeveelheid episodes over (de regulatie van) de leertaak en de kwaliteit van het model. Deze samenhang werd niet gevonden in de PC+ conditie, waar zelfs een substantieel negatief verband bleek te bestaan tussen leeruitkomsten en RLP episodes. Een verdere kwalitatieve analyse liet zien dat de regulatieve ondersteuning uit PC+ de behoefte aan RLP communicatie verminderde. PC+ groepen konden simpelweg de lijst met doelen volgen –en hun chat gegevens lieten zien dat zij dit in eerste instantie ook deden. Zodra de PC+ groepen echter begrepen wat de bedoeling van de leertaak was, concentreerden zij zich op het uitvoeren van de taak en negeerden de regulatieve ondersteuning uit de PC vrijwel volledig.

Uit dit onderzoek kan geconcludeerd worden dat de PC+ een positieve invloed heeft op de modellen van de leerlingen en hun initiële planning. De PC+ leidt echter niet tot een toename van monitoring activiteiten; om dit te realiseren lijkt extra ondersteuning nodig te zijn.

Studie 3: Het verbeteren van regulatieve ondersteuning bij onderzoekend leren

In dit onderzoek is geprobeerd monitoring te stimuleren door leerlingen tijdens het werken aan de leertaak te wijzen op de positieve effecten van het maken van aantekeningen. Hiertoe verscheen op gezette tijden een zogenaamd *pop-up* venster met daarin de suggestie aantekeningen te maken. Als leerlingen deze suggestie opvolgden, verscheen een nieuw venster met invoervelden voor de aantekeningen. Dit venster bevatte twee richtvragen. De eerste vraag nodigde de leerlingen uit de bedoeling van een bepaalde handeling of product in eigen woorden uit te leggen (bijvoorbeeld ”Wat is je onderzoeksvraag en hoe verhoudt deze vraag zich

tot je model en eindverslag?"); de tweede vraag betrof de onderbouwing van dit antwoord (bijvoorbeeld "Op welke punten komt je onderzoeksvraag overeen met de criteria die je docent zou gebruiken bij het beoordelen van je onderzoeksvraag?"). Een andere aanpassing aan de PC+ betrof de weergave van de doelen: deze werden grafisch gerepresenteerd in de vorm van een onderzoekscyclus. Door op een fase uit de onderzoekscyclus te klikken, verscheen een lijst met subdoelen voor die fase. Een laatste verandering was dat het sjabloon voor het schrijven van het eindverslag was verplaatst naar de help files.

Het onderzoek is uitgevoerd op drie *international high-schools* in Nederland. Zeventig leerlingen (16 - 18 jaar) werden op basis van hun leerprestaties voor het vak natuurkunde geclassificeerd als hoog, gemiddeld, of laag presenteerder. Vervolgens werden tweetallen van gemengd niveau gevormd, waarbij hoog- en laagpresteerders niet aan elkaar werden gekoppeld om de niveauverschillen binnen de tweetallen enigszins te beperken. Twintig tweetallen werden ingedeeld in de experimentele groep. Zij kregen de 'volledige' versie van de PC (PC+) met de hierboven beschreven regulatieve ondersteuning. Tweetallen in de controle groep (n=15) werkten met een 'lege' PC met minimale regulatieve ondersteuning (PC-). Deze leerlingen konden hun eigen doelen opstellen, bekijken, en aantekeningen maken.

De experimentele procedure kende twee wijzigingen ten opzichte van de vorige studies. Ten eerste werkten de tweetallen samen achter één computer. Ze konden direct met elkaar overleggen en communiceerden niet meer via de chat. Daarnaast kregen de leerlingen twee keer zoveel tijd als in de vorige studies. Dit was gedaan omdat in studie 2 bleek dat, ondanks de gereduceerde taakomvang, twee uur te kort is voor leerlingen om zowel een model als een eindverslag te maken.

De resultaten lieten zien dat PC+ groepen betere eindverslagen schreven en vaker en langer met de PC werkte dan de PC- groepen. PC- groepen raadpleegden vaker de help documenten en maakten betere modellen. Dit laatste verschil deed zich echter alleen voor bij tweetallen die uit gemiddeld- en laagpresteerders bestonden, wat zou kunnen betekenen dat de regulatieve ondersteuning uit de PC+ voor deze tweetallen te moeilijk was en verwarrend heeft gewerkt. Voor beide condities werd een negatieve correlatie gevonden tussen de hoeveelheid regulatieve activiteit en de kwaliteit van de modellen. Dit betekent dat tweetallen die de PC meer gebruikten, minder goede modellen maakten. Tot slot bleken het *pop-up* venster en de richtvragen weinig te worden gebruikt en geen stimulerende invloed te hebben op het maken van aantekeningen.

Studie 4: Collaboratief versus individueel gebruik van regulatieve ondersteuning

Het relatief infrequente gebruik van de PC voor monitoring zou verklaard kunnen worden uit het feit dat de leerlingen hebben samengewerkt. Van samenwerking wordt beweerd dat het een positief effect kan hebben op de regulatie en de functie van een regulatie tool zoals de PC gedeeltelijk kan overnemen. Om deze veronderstelling te onderzoeken is het gebruik van regulatieve ondersteuning door tweetallen en individuele leerlingen vergeleken. Verwacht werd dat tweetallen de regulatieve ondersteuning minder vaak zouden gebruiken, maar desondanks betere modellen en eindverslagen zouden maken.

Het onderzoek is uitgevoerd op een *high-school* in de Verenigde Staten. Leerlingen (16 - 18 jaar) werkten alleen (n=18) of in tweetallen (n=12) aan de leertaak uit studie 3. Tweetallen werden wederom gevormd op basis van hun leerprestaties voor het vak natuurkunde en werkten samen achter één computer. Zowel tweetallen als individueel werkende leerlingen hadden de beschikking over de PC+, *pop-up* vensters en richtvragen, en een sjabloon voor het schrijven van het eindverslag.

De resultaten lieten zien dat tweetallen betere modellen maakten en betere eindverslagen schreven dan leerlingen die individueel werkten. Gegevens voor het gebruik van regulatieve ondersteuning lieten een consistente en sterke trend zien in het voordeel van de alleen werkende leerlingen. De frequentie en duur van het gebruik van de PC verschilde echter niet significant tussen de condities.

Conclusie

Samengevat laten deze vier studies zien dat leerlingen ondersteuning nodig hebben bij het reguleren van hun onderzoekend leerproces. Ondersteuning in de vorm van een regulatie tool heeft een positief effect op planning. Voor monitoring werd geen verschil gevonden tussen groepen met of zonder ondersteuning. Het gebruik van een regulatie tool kan tevens een positief effect hebben op de kwaliteit van de modellen die leerlingen maken. Dit effect werd echter niet in alle studies gevonden. Uit studie 3 en 4 blijkt verder dat een sjabloon voor het schrijven van een eindverslag behulpzaam kan zijn bij het evalueren van het leerproces. Tot slot blijkt uit studie 4 dat samenwerking geen invloed heeft op het gebruik van regulatieve ondersteuning.

De resultaten voor monitoring leiden tot twee suggesties voor verder onderzoek. Ten eerste lijkt een regulatie tool zoals de PC weinig effectief te zijn voor de ondersteuning van monitoring. Andere vormen van ondersteuning (al dan niet verplicht gesteld) zijn hiervoor wellicht beter

geschikt. Welke vormen dit zijn en hoe deze het best in de leeromgeving kunnen worden opgenomen, zal moeten blijken uit verder onderzoek. Een tweede punt betreft de impliciete veronderstelling dat leerlingen even veel en even vaak zouden moeten monitoren als plannen. Deze assumptie heeft ten grondslag gelegen aan het ontwerp van de regulatieve ondersteuning in deze dissertatie. Uit het gebruik van deze ondersteuning door leerlingen kan worden afgeleid dat dit uitgangspunt wellicht onjuist is geweest. Ook hier dient verder onderzoek te worden uitgevoerd om de maximale en optimale hoeveelheid monitoring en ondersteuning te bepalen.

Een opmerkelijk resultaat was de samenhang tussen het gebruik van de PC en de leeruitkomsten. Met name in studie 3 bleek dat groepen die de PC vaker gebruikten betere eindverslagen schreven maar kwalitatief minder goede modellen maakten. Verder onderzoek zal moeten uitwijzen of dit gedifferentieerde effect te maken heeft met de afstemming tussen het soort ondersteuning en het soort leeruitkomsten. De PC biedt voornamelijk procesondersteuning en kan als zodanig de eindverslagen (waarin leerlingen hun procesgang beschrijven) op een positieve manier hebben beïnvloed. Voor het maken van het model is dit soort informatie wellicht minder relevant en zijn mogelijk de technische en domeininhoudelijke ondersteuning zoals in de help documenten werd gegeven effectiever.

References

Aleven, V.A., Stahl, E., Schworm, S., Fischer, F., & Wallance, R. (2003). Help seeking and help design in interactive learning environments. *Review of Educational Research, 73*, 277-320.

Allen, J. (1902). *As man thinketh*. Kansas City: Andrews McMeel Publishing.

Azevedo, R., & Cromley, J. (2004). Does training on self-regulated learning facilitate students' learning with hypermedia. *Journal of educational psychology, 96*, 523-535.

Azevedo, R., Cromley, J.G., Winters, F.I., Moos, D.C., & Greene, J.A. (2005). Adaptive human scaffolding facilitates adolescents' self-regulated learning with hypermedia. *Instructional Science, 33*, 381-412.

Azevedo, R., Guthrie, J.T., & Seibert, D. (2004). The role of self-regulated learning in fostering students' conceptual understanding of complex systems with hypermedia. *Journal of Educational Computing Research, 30*, 87-111.

Bera, S., & Liu, M. (2006). Cognitive tools, individual differences, and group processing as mediating factors in a hypermedia environment. *Computers in Human Behavior, 22*, 295-319.

Bransford, J.D., Brown, A.L., & Cocking, R.R. (Eds.). (2000). *How people learn. Brain, mind, experience and school* (Expanded Edition ed.). Washington D.C.: National Academy Press.

Brown, A.L. (1987). Metacognition, executive control, self-regulation, and other more mysterious mechanisms. In F. E. Weinert & R. H. Kluwe (Eds.), *Metacognition, motivation, and understanding* (pp. 65-116). Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Brown, A.L., Bransford, J.D., Ferrara, R.A., & Campione, J.C. (1983). Learning, remembering and understanding. In P. H. Mussen (Ed.), *Handbook of psychology* (Vol. 3, pp. 77-166). New York: Wiley.

Bruner, J.S. (1961). The act of discovery. *Harvard Educational Review, 31*, 21-32.

Brungardt, J.B., & Zollman, D. (1995). Influence of interactive videodisc instruction using simultaneous-time analysis of kinematics graphing skills of high school physics students. *Journal of Research in Science Teaching, 32*(8), 855-869.

Butler, D., & Winne, P. (1995). Feedback and self-regulated learning: A theoretical synthesis. *Review of Educational Research, 65*, 245-281.

Carroll, J.M. (1990). *The nurnberg funnel: Designing minimalist instruction for practical computer skill*. Cambridge, Massachusetts: The MIT Press.

Charney, D., Reder, L., & Kusbit, G.W. (1990). Goal setting and procedure selection in acquiring computer skills: A comparison of tutorials, problem solving, and learner exploration. *Cognition and Instruction, 7*, 323-342.

Chi, M., Bassok, M., Lewis, M., Reimann, P., & Glaser, R. (1989). Self-explanations: How students study and use examples in learning to solve problems. *Cognitive Science, 13*, 145-182.

Chi, M., Leeuw, N., Chiu, M., & LaVancher, C. (1994). Eliciting self-explanations improves understanding. *Cognitive Science, 18*, 439-477.

Chi, M.T.H., Feltovich, P., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science, 8*, 121-152.

Chi, M.T.H., & Glaser, R. (1985). Problem solving ability. In R. J. Sternberg (Ed.), *Human abilities: An information processing approach* (pp. 227-250). New York: W.H. Freeman and Company.

Chin, C., & Brown, D.E. (2000). Learning in science: A comparison of deep and surface approaches. *Journal of Research in Science Teaching, 37*, 109-138.

Chinn, C.A., & Brewer, W.F. (1993). The role of anomalous data in knowledge acquisition: A theoretical framework and implications for science instruction. *Review of Educational Research, 63*, 1-49.

Choi, J., & Hannafin, M. (1995). Situated cognition and learning environments: Roles, structures, and implications for design. *Educational Technology Research and Development, 43*, 53-69.

Clarebout, G., & Elen, J. (2006). Tool use in computer-based learning environments: Towards a research framework. *Computers in Human Behavior, 22*, 389-411.

Cohen, E.G. (1994). Restructuring the classroom: Conditions for productive small groups. *Review of Educational Research, 64*, 1-35.

Crook, S.M., Klein, J.D., Jones, E.E., & Dwyer, H. (1996). Effects of cooperative learning and learner-control modes in computer based instruction. *Journal of Research on Computing in Education, 29*, 109-123.

Crook, S.M., Klein, J.D., Savenye, W., & Leader, L. (1998). Effects of cooperative and individual learning during learner controlled computer-based instruction. *Journal of Experimental Education, 66*, 223-245.

Davis, E. (2000). Scaffolding students' knowledge integration: Prompts for reflection in kie. *International Journal of Science Education, 22*(8), 819-837.

Davis, E. (2003). Prompting middle school science students for productive reflection: Generic and directed prompts. *The Journal of the Learning Sciences, 12*, 91-142.

De Jong, F., Kolloffel, B., Van der Meijden, H., Staarman, J.K., & Janssen, J. (2005). Regulative processes in individual, 3d and computer supported cooperative learning contexts. *Computers in Human Behavior, 21*, 645-670.

De Jong, T. (2006a). Computer simulations: Technological advances in inquiry learning. *Science, 312*, 532-533.

De Jong, T. (2006b). Scaffolds for computer simulation based scientific discovery learning. In J. Elen & R. E. Clark (Eds.), *Handling complexity in learning environments* (pp. 107-128). Amsterdam: Elsevier.

De Jong, T., & Van Joolingen, W. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research, 68*(2), 179-201.

De Jong, T., Van Joolingen, W., Swaak, J., Veermans, K., Limbach, R., King, S., & Gureghian, D. (1998). Self directed learning in simulation-based discovery environments. *Journal of Computer Assisted Learning, 14*, 235-246.

De Vries, B. (2004). *Opportunities for reflection*. University of Twente, Enschede. Unpublished doctoral dissertation.

Dewey, J. (1938). *Logic: The theory of inquiry*. New York: Holt and Co.

Dillenbourg, P. (1996). Distributing cognition over humans and machines. In S. Vosniadou, E. De Corte, R. Glaser & H. Mandl (Eds.), *International perspectives on the psychological foundations of technology-based learning environments* (pp. 165-184). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Doerr, H.M. (1996). Stella ten years later: A review of the literature. *International Journal of Computers for Mathematical Learniing, 1*, 201-224.

Duffy, T.M., & Jonassen, D.H. (1992). Constructivism: New implications for instructional technology. In T. M. Duffy & D. H. Jonassen (Eds.), *Constructivism and the technology of instruction; a conversation* (pp. 7-12). Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Dunbar, K. (1993). Concept discovery in a scientific domain. *Cognitive Science, 17*, 397-434.

Edelson, D. (2001). Learning-for-use: A framework for the design of technology-supported inquiry activities. *Journal of Research in Science Teaching, 38*, 355-385.

Edelson, D., Gordin, D.N., & Pea, R.D. (1999). Adressing the challenges of inquiry-based learning technology and curriculum design. *Journal of Learning Sciences, 8*, 391-450.

Ertmer, P., & Newby, T. (1996). The expert learner: Strategic, self-regulated, and reflective. *Instructional Science, 24*, 1-24.

Flavell, J.H. (1971). First discussant's comments: What is memory development the development of? *Human Development, 14*, 272-278.

Forrester, J. (1961). *Industrial dynamics*. Waltham, Massachusetts: Pegasus Communications.

Ge, X., & Land, S.M. (2003). Scaffolding students' problem-solving processes in an ill-structured task using question prompts and peer interactions. *Educational Technology Research and Development, 51*, 21-38.

Georghiades, P. (2000). Beyond conceptual change learning in science education: Focusing on transfer, durability, and metacognition. *Educational Research, 42*, 119-139.

Gijlers, H. (2005). *Confrontation and co-construction; exploring and supporting collaborative scientific discovery learning with computer simulations*. University of Twente, Enschede. Unpublished doctoral dissertation.

Gijlers, H., & De Jong, T. (2005). *Confronting ideas in collaborative scientific discovery learning*. Paper presented at the American Educational Research Association, Montreal, Canada.

Gredler, M. (1997). *Learning and instruction theory into practice* (3rd ed.). New Jersey: Prentice Hall.

Greene, B., & Land, S. (2000). A qualitative analysis of scaffolding use in a resource based learning environment involving the world wide web. *Journal of educational computer research, 23*, 151-179.

Guzdial, M. (1994). Software-realized scaffolding to facilitate programming for science learning. *Interactive Learning Environments, 4*, 1-44.

Hacker, D.J. (1998). Definitions and empirical foundations. In D. J. Hacker, J. Dunlosky & A. C. Graesser (Eds.), *Metacognition in educational theory and practice* (pp. 1-23). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Hannafin, M., & Land, S. (1997). The foundations and assumptions of technology-enhanced student-centered learning environments. *Instructional Science, 25*, 167-202.

Harskamp, E., & Ding, N. (2006). Structured collaboration versus individual learning in solving physics problems. *International Journal of Science Education, 28*, 1669-1688.

Hofer, B., Yu, S., & Pintrich, P. (1998). Teaching college students to be self-regulated learners. In D. H. Schunk & B. J. Zimmerman (Eds.), *Self-regulated learning: From teaching to self-reflective practice* (pp. 57-85). New York: Guilford.

Hogan, K., & Thomas, D. (2001). Cognitive comparisons of students' stystems modeling in ecology. *Journal of Science Education and Technology, 10*, 319-345.

Howe, C.J. (1991). Explanatory concepts in physics:Towards a principled evaluation of teaching materials. *Computers and Education, 17*, 73-80.

Hulshof, C. (2001). *Discovery of ideas and ideas about discovery*. University of Twente, Enschede. Unpublished doctoral dissertation.

Jackson, S., Stratford, S., Krajcik, J., & Soloway, E. (1996). Making dynamic modeling accessible to pre-college science students. *Interactive Learning Environments, 4*, 233-257.

Jackson, S.L. (1996). *The design of guided learner-adaptable scaffolding in interactive learning environments*. Paper presented at the International Conference on Learning Sciences, Evanston, Illinois.

Jackson, T., MacKenzie, J., & Hobfol, S.E. (2000). Communal aspects of self-regulation. In M. Boekaerts, P. Pintrich & M. Zeidner (Eds.), *The handbook of self-regulation* (pp. 275-296). London: Academic Press.

Jacobs, J., & Paris, S. (1987). Children's metacognition about reading: Issues in definition, measurement, and instruction. *Educational Psychologist, 22*, 255-278.

Jonassen, D.H. (1999). Designing constructivist learning environments. In C. M. Reigeluth (Ed.), *Instructional-design theories and models: A new paradigm of instructional theory* (Vol. 2, pp. 215-239). London: Lawrence Erlbaum Associates.

Jonassen, D.H. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development, 48*, 63-85.

Kapa, E. (2001). A metacognitive support during the process of problem solving in a computerized environment. *Educational Studies in Mathematics, 47*, 317-336.

Karabenick, S.A., & Knapp, J.R. (1991). Relationship of academic help seeking to the use of learning strategies and other instrumental achievement

behavior in college students. *Journal of Educational Psychology, 83*, 221-230.
Kauffman, D.F. (2004). Self-regulated learning in web-based environments: Instructional tools designed to facilitate cognitive strategy use, metacognitive processing, and motivational beleifs. *Journal of Educational Computing Research, 30*, 139-161.
Keselman, A. (2003). Supporting inquiry learning by promoting normative understanding of multivariable causality. *Journal of Research in Science Teaching, 40*, 898-921.
Kiewra, K., DuBois, N., Christian, D., McShane, A., Meyerhoffer, M., & Roskelley, D. (1991). Note-taking functions and techniques. *Journal of Educational Psychology, 83*, 240-245.
Kirschner, P.A., Sweller, J., & Clark, R.E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential and inquiry-based teaching. *Educational Psychologist, 41*, 75-86.
Klahr, D., & Dunbar, K. (1988). Dual space search during scientific reasoning. *Cognitive Science, 12*, 1-48.
Klahr, D., Dunbar, K., & Fay, A.L. (1990). *Designing good experiments to test bad hypotheses*. Pittsburgh: Carnegie-Mellon University.
Klahr, D., Fay, A., & Dunbar, K. (1993). Heuristics for scientific experimentation: A developmental study. *Cognitive Psychology, 25*, 111-146.
Kommers, P., Jonassen, D.H., & Mayes, T. (1992). *Cognitive tools for learning*. Heidelburg, Germany: Springer-Verlag.
Kramarski, B., & Gutman, M. (2006). How can self-regulated learning be supported in mathematical e-learning environments? *Journal of Computer Assisted Learning, 22*, 24-33.
Kuhl, J. (2000). A functional design approach to motivation and self-regulation: The dynamics of personality systems and interactions. In M. Boekaerts, P. Pintrich & M. Zeidner (Eds.), *The handbook of self-regulation* (pp. 111-163). London: Academic Press.
Kuhn, D., Black, J., Keselman, A., & Kaplan, D. (2000). The development of cognitive skills to support inquiry learning. *Cognition and Instruction, 18*, 495-523.
Kuhn, D., & Dean, D. (2005). Is developing scientific thinking all about learning to control variables? *Psychological Science, 16*, 866-870.
Kuhn, D., Schauble, L., & Garcia-Mila, M. (1992). Cross-domain development of scientific reasoning. *Cognition and Instruction, 9*, 285-327.
Lan, W. (2005). Self-monitoring and its relationship with educational level and task importance. *Educational Psychology, 25*, 109-127.
Land, S. (2000). Cognitive requirements for learning with open-ended learning environments. *Educational Technology Research and Development, 48*, 61-78.
Larkin, J.H., & Simon, H.A. (1987). Why a diagram is (sometimes) worth ten thousand words. *Cognitive Science, 11*, 65-99.
Lavoie, D.R., & Good, R. (1988). The nature and use of prediction skills in a biological computer simulation. *Journal of Research in Science Teaching, 25*, 335-360.

Lazonder, A.W. (2005). Do two heads search better than one? Effects of student collaboration on web search behavior and search outcomes. *British Journal of Educational Technology, 36*, 465-475.

Leutner, D. (1993). Guided discovery learning with computer-based simulation games: Effects of adaptive and non-adaptive instructional support. *Learning and Instruction, 3*, 113-132.

Lieberman, D.A. (2004). *Learning and memory; an integrated approach*. London: Thomson Learning.

Lin, X., Hmelo, C., Kinzer, C., & Secules, T. (1999). Designing technology to support reflection. *Educational Technology Research and Development, 47*, 43-62.

Lin, X., & Lehman, J. (1999). Supporting learning of variable control in a computer based biology environment: Effects of prompting college students to reflect on their own thinking. *Journal of Research in Science Teaching, 36*, 837-858.

Linn, M.C. (1995). Designing computer learning environments for engineering and computer science: The scaffolded knowledge integration framework. *Journal of Science Education and Technology, 4*, 103-126.

Linn, M.C., Bell, P., & Davis, E. (2004). Specific design principles: Elaborating the scaffolded knowledge integration framework. In M. C. Linn, E. Davis & P. Bell (Eds.), *Internet environments for science education* (pp. 315-341). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Linn, M.C., & Hsi, S. (2000). *Computers, teachers, peers; science learning partners*. Mahwah, New Jersey: Lawrence Erlbaum Associates.

Liu, M., & Bera, S. (2005). An analysis of cognitive tool use patterns in a hypermedia learning environment. *Educational Technology Research and Development, 53*, 5-21.

Lou, Y., Abrami, P.C., & d'Apollonia, S. (2001). Small group and individual learning with technology: A meta-analysis. *Review of Educational Research, 71*, 449-521.

Lou, Y., Abrami, P.C., Spence, J.C., Poulson, C., Chambers, B., & d'Apollonia, S. (1996). Within-class grouping: A meta-analysis. *Review of Educational Research, 66*, 423-458.

Manion, V., & Alexander, J.M. (1997). The benefits of peer collaboration on strategy use, metacognitive causal attribution, and recall. *Journal of Experimental Child Psychology, 67*, 268-289.

Manlove, S., & Lazonder, A.W. (2004). Learning task regulation and working patterns in an initial discovery learning sessions with co-lab, *Paper presented at the First Meeting of the EARLI-SIG on Metacognition*. Amsterdam, The Netherlands.

Manlove, S., Lazonder, A.W., & De Jong, T. (2006). Regulative support for collaborative scientific inquiry learning. *Journal of Computer Assisted Learning, 22*, 87-98.

Manlove, S., Lazonder, A.W., & De Jong, T. (in press). Software scaffolds to promote regulation during scientific inquiry learning. *Metacognition and Learning*.

Mayer, R.E. (1998). Cognitive, metacognitive, and motivational aspects of problem solving. *Instructional Science, 26*, 49-63.

Mayer, R.E. (2002). Rote versus meaningful learning. *Theory into Practice, 41*, 226-232.
Mayer, R.E. (2003). The promise of multimedia learning: Using the same instructional design methods across different media. *Learning and Instruction, 13*, 125-139.
Nesbit, J.C., Winne, P., Damieson-Noel, D., Code, J., Zhou, M., MacAllister, K., Bratt, S., Wang, W., & Hadwin, A. (2006). Using cognitive tools in gstudy to investigate how study activities covary with achievement goals. *Journal of Educational Computing Research, 35*, 339-358.
Njoo, M., & De Jong, T. (1993). Exploratory learning with a computer simulation for control theory: Learning processes and instructional support. *Journal of Research in Science Teaching, 30*, 821-844.
Okada, T., & Simon, H.A. (1997). Collaborative discovery in a scientific domain. *Cognitive Science, 21*, 109-146.
Oliver, K., & Hannafin, M. (2000). Student management of web-based hypermedia resources during open-ended problem solving. *Journal of Educational Research, 94*, 75-92.
Osman, M.E., & Hannafin, M. (1994). Metacognition research and theory;analsysis and implications for instructional design. *Educational Technology Research and Development, 40*, 83-99.
Patrick, H., & Middleton, M.J. (2002). Turning the kaleidoscope: What we see when self-regulated learning is viewed with a qualitative lens. *Educational Psychologist, 37*, 27-39.
Penner, D.E. (2001). Cognition, computers, and synthetic science: Building knowledge and meaning through modeling. *Review of Educational Research, 25*, 1-36.
Pintrich, P. (2000). The role of goal orientation in self-regulated learning. In M. Boekaerts, P. Pintrich & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 452-502). London: Academic Press.
Ploetzner, R., Dillenbourg, P., Preier, M., & Traum, D. (1999). Learning by explaining to oneself and to others. In P. Dillenbourg (Ed.), *Collaborative learning; cognitive and computational approaches* (pp. 103-121). Amsterdam: Elsevier.
Pressley, M., Wood, E., Woloshyn, V.E., Martin, V., King, A., & Menke, D. (1992). Encouraging mindful use of prior knowledge; attempting to construct explanatory answers facilitates learning. *Educational Psychologist, 27*, 91-109.
Quinn, J., & Alessi, S. (1994). The effects of simulation complexity and hypothesis generation strategy on learning. *Journal of Research on Computing in Education, 27*, 1-10.
Quintana, C., Reiser, B., Davis, E., Krajcik, J., Fretz, E., Duncan, R., Kyza, E., Edelson, D., & Soloway, E. (2004). A scaffolding design framework for software to support science inquiry. *The Journal of the Learning Sciences, 13*, 337-386.
Reiser, B.J., Tabak, I., Sandoval, W.A., Smith, B., Steinmuller, F., & Leone, T.J. (2001). Bguile:Strategic and conceptual scaffolds for scientific inquiry in biology classrooms. In S. M. Carver & D. Klahr (Eds.), *Cognition and instruction: Twenty five years of progress* (pp. 263-305). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Renkl, A. (1997). Learning from worked-out examples: A study on individual differences. *Cognitive Science, 21*, 1-29.

Roth, W., & Roychoudhury, A. (1993). The development of science process skills in authentic contexts. *Journal of Research in Science Teaching, 30*, 127-152.

Salomon, G. (1996). Studying novel learning environments as patterns of change. In S. Vosniadou, E. De Corte, R. Glaser & H. Mandl (Eds.), *International perspectives on the design of technology-supported learning environments* (pp. 363-377). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Salovaara, H., & Järvelä, S. (2003). Students' strategic actions in computer-supported collaborative learning. *Learning environments research, 6*, 267-285.

Schauble, L., Klopfer, L.E., & Raghavan, K. (1991). Students' transition from an engineering model to a science model of experimentation. *Journal of Research in Science Teaching, 28*, 859-882.

Schauble, L., Raghaven, K., & Glaser, R. (1993). The discovery and reflection notation: A graphical trace for supporting self regulation in computer based laboratories. In S. P. Lajoie & S. J. Derry (Eds.), *Computers as cognitive tools* (pp. 319-341). Hillsdale, New Jersey: Erlbaum.

Schoenfeld, A.H. (1992). Learning to think mathematically: Problem solving, metacognition, and sense-making in mathematics. In D. A. Grouws (Ed.), *Handbook of research on mathematics learning and teaching*. (pp. 334-370). New York: Maxwell Macmillan International.

Schön, D. (1991). *The reflective practitioner* (1st ed.). Aldershot, Hants England: Arena Ashgate Publishing Limited.

Schraw, G. (1998). Promoting general metacognitive awareness. *Instructional Science, 26*, 113-125.

Schraw, G., & Moshman, D. (1995). Metacognitive theories. *Educational Psychology Review, 7*, 351-371.

Schworm, S., & Renkl, A. (2002). *Learning by solved example problems: Instructional explanations reduce self-explanation activity*. Paper presented at the Proceddings of the 24th Annual Conference of the Cognitive Science Society, Mahwah, N.J.

Shrader, G., Lindgren, R., & Sherin, B. (2000). A pedagogically-oriented analysis of the modeling process, *Annual meeting of the American Educational Research Association*. New Orleans.

Shute, V.J., & Glaser, R. (1990). A large-scale evaluation of an intelligent discovery world: Smithtown. *Interactive Learning Environments, 1*, 51-77.

Sins, P. (2006). *Students' reasoning during computer-based scientific modeling*. University of Amsterdam, Amsterdam. Unpublished doctoral dissertation.

Sins, P., Savelsbergh, E.R., & Van Joolingen, W.R. (2005). The difficult process of scientific modelling: An analysis of novices' reasoning during computer-based modelling. *International Journal of Science Education, 27*, 1695-1721.

Slotta, J. (2004). The web-based inquiry science environment (wise): Scaffolding knowledge integration in the science classroom. In M. C. Linn, E. Davis & P. Bell (Eds.), *Internet environments for science*

education (pp. 315-341). Mahwah, New Jersey: Lawrence Erlbaum Associates.
Soloway, E., Guzdial, M., & Hay, K.E. (1994). Learner-centered design: The challenge for hci in the 21st century. *Interactions, 1*, 36-48.
Stephenson, N. (1995). *The diamond age; or a young lady's illustrated primer*. New York: Bantam.
Stewart, J., Hafner, R., Johnson, S., & Finkel, E. (1992). Science as model building; computers and high school genetics. *Educational Psychologist, 27*, 317-336.
Swaak, J. (1998). *What-if: Discovery simulations and assessment of intuitive knowledge*. Unpublished PhD, University of Twente, Enschede.
Swaak, J., Van Joolingen, W.R., & De Jong, T. (1998). Supporting simulation-based learning; the effects of model progression and assignments on definitional and intuitive knowledge. *Learning and Instructions, 8*, 235-253.
Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12*, 257-285.
Teasley, S. (1995). The role of talk in children's peer collaborations. *Developmental Psychology, 31*, 207-220.
Teasley, S., & Roschelle, J. (1993). Constructing a joint problem space: The computer as a tool for sharing knowledge. In S. P. Lajoie & S. J. Derry (Eds.), *Computers as cognitive tools* (pp. 229-258). Hillsdale, New Jersey: Lawrence Erlbaum.
Van Berkum, J.J.A., & De Jong, T. (1991). Instructional environments for simulations. *Education & Computing, 6*, 305-358.
Van Boxtel, C., Linden, J., & Kanselaar, G. (2000). Collaborative learning tasks and the elaboration of conceptual knowledge. *Learning and Instruction, 10*, 311-330.
Van der Meij, J., & De Jong, T. (2006). Supporting students' learning with multiple representations in a dynamic simulation-based learning environment. *Learning and Instruction, 16*, 199-212.
Van Joolingen, W.R., De Jong, T., Lazonder, A.W., Savelsbergh, E.R., & Manlove, S. (2005). Co-lab: Research and development of an online learning environment for collaborative scientific discovery learning. *Computers in Human Behavior, 21*, 671-688.
Veenman, M., & Elshout, J.J. (1994). Differential effects of instructional support on learning in simulation environments. *Instructional Science, 22*, 363-383.
Veenman, M., Prins, F.J., & Elshout, J.J. (2002). Initial inductive learning in a complext computer simulated environment: The role of metacognitive skills and intellectual ability. *Computers in Human Behavior, 18*, 327-341.
Veenman, V.J., Elshout, J.J., & Busato, V.V. (1994). Metacognitive mediation in learning with computer-based simulations. *Computers in Human Behavior, 10*, 93-106.
Von Wright, J. (1992). Reflections on reflection. *Learning and Instruction, 2*, 59-68.
Webb, N.M. (1991). Task-related verbal interaction and mathematics learning in small groups. *Journal for Research in Mathematics Education, 22*, 366-389.

Webb, N.M., Nemer, K.M., & Zuniga, S. (2002). Short circuits or superconductors? Effects of group composition on high-achieving students' science performance. *American Educational Research Journal, 39*, 943-989.

White, B., & Frederiksen, J. (1998). Inquiry, modeling, and metacognition: Making science accessible to all students. *Cognition and Instruction, 16*, 3-118.

White, B.Y., Shimoda, T.A., & Frederiksen, J.R. (1999). Enabling students to construct theories of collaborative inquiry and reflective learning: Computer support for metacognitive development. *International Journal of Artificial Intelligence in Education, 10*, 151-182.

White, B.Y., Shimoda, T.A., & Frederiksen, J.R. (2000). Facilitating students' inquiry learning and metacognitive development thorugh modifiable software advisers. In S. P. Lajoie (Ed.), *Computers as cognitive tools* (Vol. 2, pp. 97-132). London: Lawrence Erlbaum Associates.

Williams, S.M., Bareiss, R., & Reiser, B.J. (1996). Ask jasper: A multimedia publishing and performance supported environment for design. *Paper presented at the American Education Research Association, New York, U.S.A*.

Winne, P. (1997). Experimenting to bootstrap self-regulated learning. *Journal of Educational Psychology, 89*, 397-410.

Winne, P. (2001). Self-regulated learning viewed from models of information processing. In B. J. Zimmerman & D. H. Schunk (Eds.), *Self regulated learning and academic achievement theoretical perspectives* (pp. 153-189). New York: Longman.

Zhang, J., Chen, Q., Sun, Y., & Reid, D. (2004). Triple scheme of learning support design for scientific discovery learning based on computer simulation: Experimental research. *Journal of Computer Assisted Learning, 20*, 269-282.

Zimmerman, B.J. (2000). Attaining self-regulation: A social cognitive perspective. In M. Boekaerts, P. Pintrich & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 13-35). London: Academic Press.

Zimmerman, B.J. (2001). Theories of self-regulated learning and academic achievement: An overview and analysis. In B. J. Zimmerman & D. H. Schunk (Eds.), *Self-regulated learning and academic achievement: Theoretical perspectives* (pp. 1-37). Mahwah, New Jersey: Lawrence Erlbaum Associates.