Supporting Collaborative Self-Regulation during Online Scientific Inquiry Learning

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Abstract

This paper presents the results of an experimental study which examined student’s planning, monitoring and evaluative processes during collaborative inquiry learning. Sixty-one students worked in triads or pairs to conduct a scientific inquiry with fluid dynamics. Utilizing a water tank simulation they expressed their understanding of domain principles by creating systems dynamic models. The study examined the effect of a tool designed to support collaborative self-regulation on student’s model quality. Results showed an overall positive effect for the support tool. Significant effects were found between planning variables and model quality in favor of the experimental group. Implications contribute to self-regulation research which seeks to explain how to support these processes within collaborative online inquiry learning settings.

1. Introduction

The promotion of self-regulation as a means to improve learning has played a role in our classroom curricula for the past three decades, however the advent of computerized scientific inquiry learning environments (also known as discovery learning environments) and the shift in emphasis from the objectivist view of education with ‘teacher in the center’ to the constructivist view of ‘students in the center’ brings with it the need for students to become better “active agents of their own thinking” (Kluwe, 1982). The demands placed on students within these environments are considerable. Collaborative inquiry learning requires students to work as a team of scientists to build consensus in learning complex science domains utilizing equally complex situations, simulations, datasets and models. It is this complexity which brings an even stronger need for students to be mindfully engaged while learning science with these environments. However as (Land, 2000) states this is not always the case:

“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)”

Research shows that students are usually not in fact “mindfully engaged” when it comes to learning with advanced computer technologies. The research of De Jong & Van Joolingen (1998), De Jong, Van Joolingen, Swaak, Veermans, Limbach, King & Gureghian (1998) and Land (2000) all discuss how poor self-regulatory skills often get in the way of students’ learning with the typically highly student-centered collaborative designs utilized in advanced technology environments. One of the main challenges we now face as instructional designers of these environments is how to support students in learning how to manage their own and their group’s cognitions.

The purpose of this research is to evaluate the effectiveness of a regulatory support tool called the “Process Coordinator” (PC) in assisting students in planning, monitoring and evaluating their inquiry learning with Co-Lab, an online collaborative inquiry learning environment. Prior to explicating the design of the study a brief overview of the self-regulation framework utilized in the study is given in order to contextualize the design rationale and the PC tool in Co-Lab.

2. Self-Regulation Theoretical Framework

Students with strong self-regulatory skills are better learners. These learners attend more appropriately to learning resources, make better use of learning strategies, and are more attentive when they don’t understand something (Schraw, 1998). Much research has been conducted to describe models of self-regulation. (See Jacobs & Paris, 1987, Winne & Perry, 2000; Pintrich, 2000). Azevedo, Guthrie & Seibert (2004) summarized
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three commonalities in models of self-regulation in their research on self regulated
learning with hypermedia stating that models of self regulation; (a) define the specific
processes and strategies used by students to improve academic achievement, (b) is a
cyclical and recursive process which utilizes feedback mechanisms for students to
monitor their learning and adjust accordingly, and (c) include a description of why and
how students select a specific self regulatory strategy, approach or response within
learning. In addition to these common characteristics most models specify three to four
distinct phases within the cyclical process of self regulation. These phases are planning,
monitoring, and evaluation. Figure 1 shows how this cycle can be mapped to the
regulatory processes described by Njoo & de Jong (1993) for inquiry learning. It also
shows the sub-processes which need to be supported within a tool designed to assist
students in regulating their scientific inquiry.

![Diagram of Four-phased Model of Self-Regulated Learning]

**Figure 1:** Four-phased model of self-regulated learning in Co-Lab

In the planning phase students engage in activities such as problem orientation,
setting goals for their learning and setting up a strategic plan of how to proceed.
Problem orientation entails analyzing both the task and in the initial phases, their
environment, the tools, and resources, they have to work with. Goal setting of highly
self-regulated individuals according to Zimmerman (2000) “…are organized
hierarchically, such that process goals operate as proximal regulators of more distal
outcome goals” (p. 17). Thus it is expected that students would benefit from a
hierarchical structure of goals when trying to foster self-regulation. Assisting students
in setting subgoals helps them develop strategic plans for accomplishing goals.
Strategic planning processes include students’ ideas for how to approach goals and
subgoals, as well as management of their collaboration and learning objects.

Once students have worked on a plan they engage in task execution and monitoring.
Students recursively monitor and adjust their task approach based on feedback which is
either generated by self (group) judgments, or from salient cues found in the learning
setting (Butler & Winne, 1995). Specifically students engage in control and observation
of their comprehension, planning, strategy execution, and organization. Comprehension
monitoring includes a student determining their level of understanding pertaining to the
domain knowledge, task (as specified during the planning phase), and resources.
Monitoring of planning entails students keeping track of where they are on a particular
goal or subgoal. When students engage in observation and control of their strategy
execution they may attend to self or group member explanations, attention focusing,
and cognitive strategy execution (Zimmerman, 2000). Self or group member
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explanations entail a student describing to himself or to another group member how to proceed during task execution in order to optimize effort. Attention focusing is the act of concentration on essential characteristics of the task at hand. Finally cognitive strategy execution during monitoring can take the form of general rehearsal, elaborative, or organizational (Weinstein & Mayer, 1986) actions in which students break down a learning task to its essential parts and organize material in a way meaningful to them. Specific cognitive strategies during monitoring may include the processes of note-taking, reflective questions and discussions, or summarization. Ideally, students will assess how well a particular strategy is working in comparison to task conditions (time, resources), comprehension, and task attainment. Monitoring of organization relates to statements or actions meant to track organizational details such as saving artifacts, and coordination of collaborative effort.

During the final phase students engage in evaluation of both their learning process and the learning outcomes. 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 outcomes involves student assessment of learning objects and outcomes they have created. In Co-Lab these include models or datasets from experiments. Generally students evaluate by comparing how well the information they have acquired fits with the goals they have set during planning or other task criteria. Goal orientation will often determine the criteria students use to evaluate their performance and their learning (Zimmerman, 2000, Pintrich, 2000, Ng & Bereiter, 1995) According to Zimmerman (2000) there are four criteria, learners might use to evaluate their performance and their learning. These are, previous performance, normative, collaborative, and mastery. Evaluation based on previous performance entails a student comparing their own current performance with their past performance or effort. A normative evaluation criterion has a learner making judgments about their performance in comparison to others. Collaborative criteria judgments are made in group learning settings and will often be an evaluation of the learner’s role in the team effort. Finally, when students adopt a mastery criterion they will use a graduated sequence of self judgments about one’s performance in relationship to a novice expert continuum. The ultimate goal of this criteria and orientation is the acquisition at an “expert” level of the skill or domain. Taking a mastery criteria or goal orientation is considered best for deep processing of domains and skills and has been found to be promoted by process goal hierarchies as they give students a ready index of mastery and criteria (Zimmerman, 2000).

3. Design Implications

A prior study with Co-Lab (Manlove, Lazonder & De Jong, 2004) examined student’s unprompted and unsupported self regulation. It was found that students performed very few of the activities discussed in the framework above. This result taken with the complexity of tasks students are expected to perform in inquiry learning environments (see for example, De Jong & Van Joolingen, 1998; Land, 2000) indicates the need for support and scaffolds within these environments. Towards this end, implications were drawn from the processes described above in order to design support into the main tool used within Co-Lab for self-regulation, the PC.

These implications indicate that students need process support (Lin, Hmelo, Kinzer & Secules (1999) for their inquiry learning which promotes and directs them to (1) set hierarchical goals, (2) form a strategic plan, (3) highlight potential strategies which are useful for them during their learning, (4) provide a means for goal tracking such as note taking facilities which can be appended to specific goals and sub-goals, and (5) provide a place for evaluating both their outcomes and their performance. The PC was designed to include what Lin et al (1999) call a process model, and a process display type support. The process model being in this case the hierarchy of goals and subgoals which is essentially a map for conducting an inquiry and modeling and a process
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display in the form of a history view where student generated actions are listed so they can see and track their progress. A more complete description of the PC is found in the materials section of this paper.

The current research seeks to determine if a fully specified PC which is designed according to the implications listed above, will show increased instances of planning, monitoring and evaluation of the learning task, and better modeling quality. The study employs a control group experimental design with assignment. Students in the control group had access to a PC tool which had no content (PC–), but had full functionality. The experimental group had access to a fully specified version of this tool (PC+) which included a hierarchy of goals and subgoals as well as hints which were specific to each step. Students from the PC+ group were expected to produce more instances of planning and monitoring as evidenced in their PC use and chat dialogues in comparison to the PC– students. PC+ groups were further assumed to produce higher quality models and better quality reports than PC– groups.

4. Method

4.1 Participants

The participants of this study were 61 high-school students (aged 16-18) within four study tracks: nature and technology, nature and health, economics, and cultural studies. Due to the impact which prior knowledge has on learning, and the importance of creating heterogeneous ability groupings, a matching process was instituted to ensure that the nature and technology students were evenly distributed with the other tracks in the group formation. Nineteen triads and two dyads were created once track matching was complete. They were randomly assigned to experimental conditions, leading to 12 PC+ groups and 11 PC– groups.

4.2 Materials

Co-Lab was installed on the study participants’ high school network. Materials from Co-Lab’s greenhouse gasses and water management modules were utilized. The greenhouse gas module materials were used for the introduction to Co-Lab and for an introduction to systems dynamic modeling. Materials from the water management module were used during the experiment. Due to time constraints and the general complexity of the target model of the water tank simulation within Co-Lab, the target model for the experiment was restricted to focusing on outflow only (see Figure 2). A more detailed explanation of the Co-Lab environment can be found in Van Joolingen, De Jong, Lazonder, Savelsbergh, & Manlove (2005).

Figure 2: Target model for the experimental task
Figure 3 shows an annotated screenshot of the PC used by the PC+ groups. The goal tree contains a set of goals and subgoals that outline the phases students should go through in performing their inquiry. Each goal and subgoal came with an elaborate description students could view by clicking the “Description” tab. For each subgoal there were one or more hints, which housed answers to frequently asked questions (e.g., how to specify a hypothesis). The “Notes” tab opened up an entry field where students could type text, for instance to write down intermediate results. Notes are attached to the active (sub)goal and can be inspected by clicking the “History” tab. As the left-hand side of Figure 4 shows, this action changes the outlook of the PC such that it reveals the goals and the notes students attached to it in chronological order. Clicking the “Generate report” tab again changes the outlook (see Figure 4). Students now see the goal tree, the history window and a report template that can be filled out by typing text and copying notes from the History window. The PC+ differed from the PC− in that the former contained a full list of (sub)goals, descriptions, hints, and a report template. The remaining features were similar across conditions.

Co-Lab also housed materials for the students to use during the experiment. The greenhouse gas building was setup with a preset model for the students to explore during the modeling introduction. A mission statement for both the greenhouse gas building and the water management building were also specified. These are explained in more detail in the procedure section.

4.3 Procedure

The experiment was conducted over three sessions that were run in a large computer lab at the school. Group members were distributed around the room in order to enforce electronic rather than face to face collaboration. The first session involved an introduction to Co-Lab and an introduction to modeling. The second and third sessions had students working on a collaborative discovery learning task. These sessions are described below.

![Figure 3: Fully specified Process Coordinator (PC) used in the PC+ condition (goal tree view)](image)
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Figure 4: Process Coordinator (PC) History view (left-hand side) and Report view (right-hand side)

First Session: Introduction to Co-Lab and System Dynamics Modeling
In the first session, students were given an observer lead PowerPoint overview of Co-Lab showing tools and navigation. After the introduction students were seated in a computer lab and directed to work individually on an introduction to modeling. In order to control for the difficulties students might have with modeling which might interfere with a true assessment of the overall use of Co-Lab in a natural setting, it was deemed necessary to provide this introduction. The modeling introduction had students work individually through reading materials which explained systems dynamic modeling language and symbols as well as the use of the model editor in Co-Lab. Students were given a simplified model based on the materials from Co-Lab’s green house gas module to work with for this introduction. Students completed the individual modeling introduction within fifteen to twenty minutes.

Second and Third Sessions: Experimental Task
In the second and third sessions students began working on the inquiry learning task within the water management building. Students were seated in a computer lab with group members dispersed throughout the room in order to prevent face-to-face communication. Students were directed to begin by looking at the mission statement (see Figure 5), 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 to the groups on technical issues only.

4.4 Coding
Three different types of data were gathered for this study; (1) Model quality scores, (2) PC activity, and (3) verbal protocol data from logs of student’s chat files. This section elaborates the coding procedures used with these data types. Following this section, data analysis techniques are presented.
Your own swimming pool in your back yard! Cool! But...you must clean your swimming pool and this means you have to be able to empty it. With a middle-sized swimming pool this can take a whole day!

This seems to Professor Pregunta, the main character in this assignment way too long. He wants to buy a swimming pool and asks how long before the swimming pool is emptied. Because the pool supplier can’t give an answer professor Pregunta decides to do some research himself. He has gone to his neighbors to ask for information and he wants you to find out why one swimming pool empties faster than another.

In order to give Professor Pregunta good advice you must understand what happens when a swimming pool empties. Naturally the water level drops. But how quickly? And what influence does the diameter of both the swimming pool and the drainpipe play?

In order to give an answer to these questions you should experiment with a simulation of an bucket (a sort of mini-swimming pool). An at the beginning of each experiment fill it to the top, make sure the tap is closed, and drain the bucket so that there is no more water in it. Do systematic experimentation, so that you can see what influence the above mentioned factors have on the outflow.

Armed with this knowledge you can make a model of the relationships between the key factors.. With this model Professor Pregunta can decide which kind of swimming pool he wants to buy. Go to the meeting room and open the process coordinator to first make a plan of how you will approach this task.

**Figure 5:** Assignment used for the experimental task

**Model Quality**

Model quality was assessed from the groups’ final models using a slightly adapted version of the methodology by Löhner, Van Joolingen & Savelbergh (2003). Minor changes were deemed necessary because students in this experiment had to build qualitative models as their final product instead of the quantitative models used in Löhner et al’s methodology. Model quality scores were thus computed from the number of correctly specified variables and relations. With regard to the variables, 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. 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. One additional point was given if the direction of a relation was correct, and a third point could be earned if the type of the relation was correct. In all cases, “correct” was judged from the target model shown in Figure 2. The maximum model quality score was 26; 10 points for the variables and 16 points for the relations. To assess interrater reliability, two raters scored 10 models that were randomly selected from the total number of available models. Interrater reliability estimates for constituent parts of the model quality score were high, with Kappa values ranging from 0.90 to 1.00.

**Regulatory Activities**

In order to assess whether students were planning, monitoring and evaluating during their two sessions, PC actions were associated with each of these processes. Planning was defined by four actions; (1) viewing of specific goals, (2) adding goals or subgoals, (3) viewing hints, and (4) viewing the goal descriptions. Three actions were associated with monitoring activities; (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 Protocol Data**

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. Utterances are separated by a “perceptible pause” which in case of synchronous online communication often comes down to sending the message. Each utterance was then classified according to...
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 pertain 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. For further elaboration of these distinctions please see Appendix A.

Beyond the utterance coding, conceptually related utterances were merged into episodes. Consistent with Van Boxtel (2000), an episode was operationally defined as a set of expressions that is meaningful at the content level. Episodes were coded via sets of cognitive, regulative, affective or procedural utterances (off task utterances were not grouped into episodes.) The definitions listed above for the utterance level coding were also used for cognitive, affective and procedural episode definitions. Regulatory episodes however, were further split into two distinctions: regulation of collaboration and regulation of the learning task. Regulation of collaboration episodes pertain to any discussion of collaborative work and include division of tasks, greetings, or expressions asking what group members are doing and where group members are in the environment. Regulation of the learning task episodes in contrast entail conversations regarding planning or approaching the learning task, monitoring progress, learning products, or comprehension as well as evaluation type conversations regarding learning products or processes. Please see Appendix B for examples of the regulatory episodes. 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 episode formation; agreement estimates (Cohen’s Kappa) for the classification of utterances and episodes were .65 and .95 respectively.

4.5 Data Analysis

Technical difficulties in the environment and absentee students prevented analysis of the full sample in certain cases. For this reason analysis of each of the data types was conducted on a case by case basis for inclusion. Within model quality and PC actions three groups were excluded from the analysis, 2 were PC+ groups and 1 was a PC- group. Within the verbal protocol analysis of student chat files, three PC+ groups and 2 PC- groups had to be removed from the sample.

Between group differences were assessed by means of t-tests and, when variables had a skewed distribution, Mann-Whitney U tests. Correlations were computed between model quality scores, PC actions, and verbal protocol data. Both individual PC action frequency data and composite scores were utilized. As this study used a relatively small sample, there is a fair chance that true effects will not show in the analyses (i.e., beta Type II error). To avoid overlooking these effects we report $p<.10$ as statistically significant.

In order to determine potential explanations for some of the correlational results, qualitative analysis of the PC+ condition groups’ cognitive and regulation of the learning task episodes was undertaken in order to determine the nature of these dialogues. This analysis entailed examining these episode types for topic patterns.
5. Results

5.1 Model Quality

As most student groups were unable to attain complete models by the end of session 2, their models are characterized as being intermediate models. The seeming lack of time might account for the fact that the average model quality scores displayed in Table 1 were somewhat low. The scores nevertheless seem to differentiate between groups as shown by the considerable range in scores. Mann-Whitney U tests further demonstrated that PC+ groups achieved significantly higher model quality scores than PC− groups (Z(17) = −2.07, p<.05). This difference probably arose because PC+ groups were better at specifying variables (Z(17) = −1.77, p<.10); the scores for relations were not significant (Z(17) = −1.57, p=.14).

Table 1: Mean Model Quality Scores

<table>
<thead>
<tr>
<th></th>
<th>PC+</th>
<th></th>
<th>PC−</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>Range</td>
<td>M</td>
</tr>
<tr>
<td>Variables</td>
<td>5.50</td>
<td>1.77</td>
<td>3-8</td>
<td>4.00</td>
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<tr>
<td>Relations</td>
<td>3.88</td>
<td>2.70</td>
<td>0-7</td>
<td>1.78</td>
</tr>
<tr>
<td>Total</td>
<td>9.38</td>
<td>4.03</td>
<td>4-15</td>
<td>5.78</td>
</tr>
</tbody>
</table>

5.2 Regulatory Activities

Planning

Table 2 shows the means and standard deviations for the PC actions associated with planning by condition. On the whole, PC+ groups performed more planning actions than the PC− groups did (t(16) = 4.97, p<.01). Analyses of individual PC actions revealed that groups in the PC− condition added more goals than did their counterparts in the PC+ condition. However, a comparison of the mean number of added goals did not produce statistical significance; t(16)=1.39, p=.19). The number of goals added ranged from zero to eight, with only one group in the PC+ condition adding goals versus five groups in the PC− condition. In contrast, students in the PC+ condition utilized the PC significantly more for viewing specific goals (t(16)=5.09, p<.01), goal descriptions (t(16)=2.35, p<.05) and hints (t(16)=2.74, p<.05). The range of frequencies for viewing specific goals was between 0 and 86 times, for viewing goal descriptions, 0 to 59 times, and finally for viewing hints the frequency range was between 2 and 34 times. All groups in the PC+ condition made at least some attempt at viewing goals, descriptions and hints.
Table 2: Mean Scores for PC Actions

<table>
<thead>
<tr>
<th></th>
<th>PC+</th>
<th></th>
<th>PC−</th>
<th></th>
</tr>
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<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Planning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Add goals</td>
<td>0.67</td>
<td>2.00</td>
<td>2.33</td>
<td>3.00</td>
</tr>
<tr>
<td>View goals</td>
<td>47.78</td>
<td>26.47</td>
<td>2.56</td>
<td>3.32</td>
</tr>
<tr>
<td>View goal descriptions</td>
<td>20.22</td>
<td>16.63</td>
<td>6.78</td>
<td>4.15</td>
</tr>
<tr>
<td>View hints</td>
<td>19.78</td>
<td>9.03</td>
<td>10.22</td>
<td>5.26</td>
</tr>
<tr>
<td>Total Planning</td>
<td>88.4</td>
<td>39.1</td>
<td>21.9</td>
<td>9.5</td>
</tr>
<tr>
<td>Monitoring</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Add notes</td>
<td>3.89</td>
<td>6.07</td>
<td>2.78</td>
<td>4.00</td>
</tr>
<tr>
<td>Mark goal complete</td>
<td>0.00</td>
<td>0.00</td>
<td>0.22</td>
<td>0.44</td>
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<tr>
<td>View history</td>
<td>14.78</td>
<td>11.30</td>
<td>14.00</td>
<td>12.21</td>
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<tr>
<td>Total Monitoring</td>
<td>18.7</td>
<td>15.5</td>
<td>17.0</td>
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<td>Evaluation</td>
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</tr>
<tr>
<td>Generate report</td>
<td>0.00</td>
<td>0.00</td>
<td>0.22</td>
<td>0.00</td>
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<tr>
<td>Write in report</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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</tr>
</tbody>
</table>

**Monitoring**

The data in Table 2 show only slightly higher monitoring activities in the PC+ group, however no statistically significant difference with total number of PC actions associated with monitoring between conditions existed (t(16)=0.23, p=.82). There is a marked difference between amount of planning and monitoring activities which indicates that students did not use the PC as much for reflecting on their progress and comprehension as they did for problem orientation, goal setting and strategic planning.

**Evaluation**

The data in Table 2 suggest that the students did not reach a point in their inquiry where they felt the need to evaluate their activities with the PC tool. In fact only one group attempted to generate a report but did no writing in the report. This action can then be seen as an exploration of the PC’s report function rather than as an actual evaluation activity. For this reason evaluation activities will be excluded from the remaining analyses.

**5.3 Verbal Protocol Data**

Across two sessions, 16 groups wrote 7274 chat messages containing 7456 utterances, which were merged into 887 episodes. Statistics at the utterance level confirmed the findings from Manlove et al. (2004) that students overall engaged in a higher percentage of regulatory utterances than any other category, at 48.35%, compared to 3.16 % for affective, 11.67% for cognitive, and 17.55% for procedural. The remaining 20.28% of the utterances were off task; these statements were not grouped into episodes and were therefore excluded from the analyses.
Table 3: Mean Percentage of Chat Episodes

<table>
<thead>
<tr>
<th></th>
<th>Affective</th>
<th>Cognitive</th>
<th>Procedural</th>
<th>Regulation</th>
<th>Regulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>PC+</td>
<td>1.74</td>
<td>1.98</td>
<td>12.65</td>
<td>5.69</td>
<td>18.28</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>33.72</td>
</tr>
<tr>
<td>PC-</td>
<td>2.76</td>
<td>1.61</td>
<td>7.03</td>
<td>2.96</td>
<td>19.21</td>
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<tr>
<td></td>
<td></td>
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<td></td>
<td>39.35</td>
</tr>
<tr>
<td>Entire sample</td>
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<td>1.82</td>
<td>9.84</td>
<td>5.25</td>
<td>18.75</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>36.54</td>
</tr>
</tbody>
</table>

Table 3 shows the mean percentages of chat episode categories by condition. While PC- groups engaged in slightly higher instances of regulation of collaboration, this difference was not statistically significant (t(14)=1.24). Groups in both conditions also produced a comparable proportion of episodes indicating regulation of the learning task (t(14)=.48). Analyses for the other episode categories showed that instructional condition had an effect on cognitive episodes (t(14)= 2.48, p<.05) with PC+ groups showing a higher proportion of task related talk than PC- groups. The proportions of affective and procedural episodes were comparable across conditions (t(14)=-1.13, and t(14)=-.34 respectively).

5.4 Correlating Regulatory Activities

PC Actions & Model Quality

As shown in the regulatory activities section, PC planning actions were found to be statistically significant by condition, whereas monitoring activities were not. In order to investigate the potential relationship between model quality scores and the PC planning actions correlational analysis was run between these variables. Total planning and monitoring scores did not correlate with model quality scores in both conditions (r=.34 < r < .16).

However within the PC+ condition, a significant correlation was found with analysis run between the individual planning variables and model quality. Seemingly groups who viewed goal descriptions (r=.58, p=1.10) also had higher model quality scores. In the PC- condition no significant correlations were found between model quality and PC actions. In addition no correlations were found to be significant between the individual monitoring variables and model quality (r=.04, p=.89).

Verbal Protocol Data & Model Quality

Correlational analysis was also run between the verbal protocol data and model quality scores. Within the PC+ condition, a significant negative relationship was found between percent of regulation of the learning task episodes and model quality (r = -.59, p<.10) indicating that the more students talked about planning or monitoring the lower their model quality scores tended to be. This result suggests that PC+ groups had access to a tool which supports regulation of the learning task and thus had less need to openly discuss their plans or monitoring activities.

The PC- condition showed a substantial correlation between percentage of regulation of the learning task episodes and model quality (r=.94, p<.01). This indicates that groups in the PC- condition which engaged in a high degree of talk related to planning, monitoring and evaluation of their inquiry also had high model quality scores. In converse however, it seems that the more students discussed their team work the lower their model quality scores. A significant negative correlation was found between proportion of regulation of collaboration episodes and model quality scores (r=.76, p<.01). Finally a significant relationship was found between percent of cognitive
episodes and model quality \((r=0.61, p<0.10)\) indicating that groups who engaged in
cognitive talk also had high model quality scores.

**Verbal Protocol Data & PC Actions**

Correlational analysis was conducted between the verbal protocol data and the total
planning and monitoring variables. Within the entire sample, total planning correlated
significantly with percent of cognitive episodes \((r=0.51, p<0.05)\), indicating that students
who frequently viewed the goal tree, goal descriptions and hints, and added goals in the
PC also had higher instances of cognitive episodes. Unfortunately this was not born out
in the correlational analysis by condition. In addition, no correlations were found
between total monitoring scores and the verbal protocol data within the entire sample or
the analysis by condition.

Further correlational analysis was run between the verbal protocol data and the
individual planning and monitoring variables (vs. the total planning and monitoring
scores). One significant negative correlation was found in the PC+ group which shows
similarity to the relationship found between the verbal protocol data and model quality.
A negative correlation was found between viewing goal descriptions and percent of
regulation of the learning task episodes \((r=-0.89, p<0.01)\). This indicates that the more
groups looked at goals in the PC the less they felt the need to engage in regulatory talk.
No significant correlations were found with the individual planning variables and
percent of episodes in the PC- condition.

The quantitative analysis gives partial support for this study’s hypothesis that
students who engage in a high degree of regulatory talk would have better model
quality scores. This hypothesis does hold true for the PC- group. However it doesn’t
hold true for the PC+ group. In fact the opposite was true, the more students in the PC+
condition, engaged in regulatory talk the lower their model quality scores seemed to be.
Why? It seems plausible that students in this condition did not need to discuss their
planning or monitoring since these activities were taken care of within the PC itself, and
thus students in this group were free to engage in cognitive talk. However, this means
that a high degree of cognitive talk should have correlated with model quality scores, as
it almost did in the PC- condition, but this was not found in the analysis. In order to
determine why this correlation was absent and explain why regulatory talk in the PC+
group was associated with lower model quality scores a qualitative analysis of the
nature and topics of student’s regulatory and cognitive episodes was undertaken.

5.5 **Qualitative Analysis of Verbal Interaction**

**Regulation of the Learning Task Episodes**

Qualitative analyses confirmed the notion that the support offered by the PC+
reduced the need for regulative talk. 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 episode in which students proposed to consult the PC to plan
their inquiries. The following series of episodes (Excerpt 1) is one of the best
illustrations of how a PC+ group simply followed the goal tree within the PC. Line 8
shows the group starting with the first top level goal in the PC; “Before you begin”. Lines 11, 17, and 28 have the group proceeding to address the subgoals to this goal.
Excerpt 1

1. Bryan: We need to go to the process coordinator.
2. Bryan: Go there then.
3. Bryan: To make a plan.
   ... ...
4. Mitchell: Now, Dustin, do you have any idea what we need to do?
5. Bryan: Okay guys, we should first figure out variables and relationships.
6. Dustin: I’ve got some idea.
7. Dustin: but only a little.
   ... ...
8. Bryan: Should we begin with “Starting out”?
9. Bryan: Yes, exactly the first two things we know right??
10. Bryan: Right??
11. Bryan: Now, “Create a common understanding”
   ... ...
12. Bryan: Mitchell, how should I write the assignment in our own words?
14. Bryan: Then fill what’s there in, save it and then we can continue.
15. Bryan: Okay?
   ... ...
16. Bryan: Okay the next one.
17. Bryan: “Identify variables”
   ... ...
22. Bryan: The question is “what are the central variables?”
23. Bryan: Mitchell can you put them in under the “notes”?
   ... ...
24. Dustin: Two factors, the diameter of the tank and the diameter of the drain pipe.
26. Bryan: Guys, it’s saved (you can find it under history).
27. Mitchell: But changing it doesn’t really work.
28. Bryan: Next, “identify relationships?”
29. Mitchell: I don’t understand this, first they say you can examine which factors have influence and then they say what are the factors? Some research…
30. Dustin: We can simply begin with the experiment?
31. Bryan: Now the relationships between the factors.
32. Mitchell: Okay begin then.
33. Bryan: How about I put this: The diameter of the drain pipe determines how fast the water drains which in turn relates to the amount of water.

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. Remaining topics of the regulation of the learning task episodes covered mostly instances of ad-hoc planning, (“We need to check the variables in the lab”), expressions of comprehension failure (“I don’t understand this, it’s so confusing”), helpseeking (“Go and ask for help”or “Go check the help files”) and learning object management (“Did you save that graph?”).

Cognitive Episodes

Qualitative analysis also sought to reveal why the cognitive episodes did not correlate with model quality scores in the PC+ condition as they came close to in the PC- condition. Prompted by the PC goals, PC+ groups set off by exploring the variables in the simulation and discussing their settings and specifications. 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 2 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 2

1 Dustin You have to begin with a full watertank
2 Mitchell I don’t know, but we have to have a formula for the inflow and outflow, because those are variable
3 Bryan Yes they are variable
4 Mitchell But you have selected a fixed unit
5 Bryan Me?? Should have been by accident
6 Mitchell Nope
7 Mitchell There you have 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 How should it be then?
12 … …
13 Bryan We also need to put in some sort of relationships!

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 3), but paid no attention to the overall model structure. The patchy knowledge that resulted from these discussions was used to model the influence of diameter of the drain on the 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 3

1 Karl The relation
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 every time just as full
6 Karl So...I don’t 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 4.

Excerpt 4

1 Ben I need the watervolume
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’s at 0.500 m
8 Sheryl And diameter is 0.44m
9 Ben Thanks

6. Discussion

In order to offset the complexities found in collaborative inquiry learning environments with simulations, instructional supports are necessary, particularly when it comes to helping students engage in regulatory actions (Land, 2000; Lin, 2001; LeBow, 1993). The hypothesis of this study was that a fully specified PC would help
students create better models, show increased instances of planning, monitoring, and evaluation activities, and prompt more regulatory talk. As reported the PC showed an overall positive effect on planning and model quality in the PC+ condition, however mixed results with regard to monitoring, evaluation and regulatory talk of the students were also found.

Students in the PC+ group did have significantly higher model quality scores than students in the PC- group. One of the potential reasons for this may be the increased problem orientation and strategic planning activities of students in this group. Results show that the PC+ groups did engage more in overall planning actions, in particular adding goals and viewing goal descriptions. These groups also tended to have higher model quality scores than those in the PC-group. As described in the theoretical framework, research on providing learners with process goals and subgoals have been found to improve both students’ acquisition of academic skill and are a characteristic of highly self-regulated individuals (Kitsantas, 2003; Zimmerman, 2000). The use of a process model might also have contributed to the PC+ group’s model quality since process models call student’s attention to the salient steps of an activity as an expert might conduct it (Lin et al. 2001). The use of goals and subgoals as prompts within the process model assisted students in appropriate thinking for inquiry conduction and model making. Therefore it seems the PC was successful in scaffolding student’s problem orientation and planning which in turn led to higher quality models.

The presence of the PC may have affected model quality in a different way as well. While the PC- group held true to the study’s prediction that a higher degree of regulation of the learning task talk would lead to higher model quality, this result was not found in the PC+ group. In fact the more PC+ students viewed goal descriptions the less they engaged in regulation of the learning task discussions, suggesting that the fully specified PC may have taken the place of regulatory talk. This in turn may have freed up PC+ groups to engage in significantly more cognitive discussions than their counterparts.

However the analyses show instructional effect of condition on percent of cognitive episodes in favour of the PC+ condition, a significant correlation between model quality and cognitive episodes was found only within the PC- group. 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 two of these groups focused not on overall model structure but, following the PC’s goal tree, spent a great deal of time identifying variables, and relationships between pairs of variables. The third group seemed to rely solely on the expertise of one student within the group to generate a high quality model despite relatively few cognitive utterances. This result lends support for the need to encourage student engagement with model structure in intermediate phases of their learning.

Analysis revealed that students showed very little evidence of reflection in terms of monitoring activities or within their discussions. The qualitative analysis showed PC+ students often relied on the PC to attain task understanding. After task understanding was reached they then abandoned it, as evidenced by the scant use of the PC towards the end of their sessions as well as by the low PC actions associated with monitoring. This approach taken by a majority of PC groups is typical of what Ng & Bereiter (1995) call adopting a “task completion” level goal orientation: “Students whose protocols exhibited mainly task completion goals seemed to look at learning as identifying what needed to be done and then doing it” (p. 371). A consequence of taking a task-completion level of goal orientation is that students engage in little monitoring, have generally lower academic performance and little ability to transfer knowledge gains to new situations in comparison to students who adopt a mastery or knowledge-building level of goal orientation (Shimoda, White & Frederiksen, 2001; Zimmerman, 2000)

Evaluation via the PCs report function was also not performed by the students. Only one PC+ group attempted to use the PC’s report function and that was deemed an
exploratory activity. A prior one-session study with Co-Lab (Manlove et al., 2004) utilized the water tank module and had students attempt to achieve a full model of the water tank with both outflow and inflow incorporated in the task. Students were unable to attain full models within that session. Thus, it seems that, despite the efforts to restrict the task and the model for this experiment, two sessions were not enough for students to formally evaluate their progress with the PC. Students may not have felt they were at a point in their inquiry where they could utilize the report function of the PC. Future research with Co-Lab should therefore seek to include three or four experimental sessions in order for students to have complete and tested models which can be evaluated in light of the planning and monitoring processes with the PC, and so the PC’s report function can be fully evaluated.

Overall the results of this study indicate a positive effect for the PC tool to support self-regulation of collaborative inquiry learning activities of students particularly for planning and better model quality. It is clear that those students who had access to a hierarchy of goals and hints performed increased planning activities, but results were not so conclusive for an increase in monitoring activities. Future research should therefore investigate the use of explicit prompts (Lin et al 1999) for monitoring activities such as checking comprehension and strategy deployment such as note-taking. Alternately, feedback loops are the trigger for students to engage in monitoring, evaluation and adaptation of their learning processes (Butler & Winne, 1995). Research also needs to investigate where feedback loops could be augmented as more “natural” prompts in the other tools within Co-Lab in order to enhance the use of the PC.

Land (2000) states that caution is needed against relying solely on embedded support for the metacognitive activities of self-regulation within open ended learning environments. Just because a tool exists to support self-regulation, does not mean that students will use it. This points to the problem of metacognitive awareness (Schraw, 1998): students often are ignorant of their needs for assistance or are approaching a task inefficiently especially in light of the multiple activities of hypothesis generation, experimentation, data analysis and modeling they are required to do in Co-Lab. Future research needs to address whether or not imposed use of the PC at key points within and across student sessions might assist students in becoming more aware of the difficulties they are having and how to correct them.
References


### Appendix A: Coding Schema for Chat Utterances

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive (C)</td>
<td>Utterances referring to (activities related to) the content of the learning task</td>
<td>• Tank_level / Hole_diameter&lt;br&gt;• My tank is half empty, yours too?</td>
</tr>
<tr>
<td>Regulative (R)</td>
<td>Utterances pertaining to the planning, monitoring and evaluation of the learning task</td>
<td>• We should specify the correct parameters in the simulation&lt;br&gt;• Wait, this isn’t leading us anywhere&lt;br&gt;• Let’s see what we’ve got so far</td>
</tr>
<tr>
<td></td>
<td>Utterances pertaining to the regulation of the collaboration</td>
<td>• Hi guys, I’m in the Lab&lt;br&gt;• Let’s go to the Hall&lt;br&gt;• Pass on the control, please&lt;br&gt;• What are we going to do next?&lt;br&gt;• Shall I draft a model?</td>
</tr>
<tr>
<td>Affective (A)</td>
<td>Utterances expressing students’ feelings toward the task, the software, and the collaboration</td>
<td>• This is too difficult&lt;br&gt;• It’s a bit vague, isn’t it&lt;br&gt;• Nice assignment!</td>
</tr>
<tr>
<td>Procedural (P)</td>
<td>Utterances concerning the technical operation of the environment and its tools</td>
<td>• Press the button under the names&lt;br&gt;• Can you see the simulation too?&lt;br&gt;• Where can I find the process coordinator?&lt;br&gt;• Stop scrolling !!!!!</td>
</tr>
<tr>
<td></td>
<td>Utterances expressing a request for help from the experimenter</td>
<td>• Ask somebody then</td>
</tr>
<tr>
<td>Off task (O)</td>
<td>Utterances not related to the learning task or the collaboration (social talk)</td>
<td>• Look outside, its raining</td>
</tr>
<tr>
<td></td>
<td>Uncodeable messages (chat talk)</td>
<td>• f:lgah;ko</td>
</tr>
</tbody>
</table>
### Appendix B: Coding Schema for Chat Episodes

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Regulation of the Learning Task</strong></td>
<td>A series of utterances which pertain to planning, monitoring or evaluation of the learning task.</td>
<td>• <strong>Planning</strong>&lt;br&gt;Mick Now, Dane, do you have any idea what we should do?&lt;br&gt;Brett Okay guys, we have to first determine the variables and the relationships.&lt;br&gt;Dane Yes, an idea but only a little</td>
</tr>
<tr>
<td><strong>Monitoring</strong></td>
<td></td>
<td>• <strong>Room Change</strong>&lt;br&gt;Lynn Shall we go to the meeting room? Now?&lt;br&gt;Rafe I’m in the meeting room&lt;br&gt;Laura Yes now&lt;br&gt;Lynn Okay, now I’m here</td>
</tr>
<tr>
<td><strong>Regulation of Collaboration</strong></td>
<td>A series of utterances which pertain to organization of group work, room changes, and/or division of tasks</td>
<td></td>
</tr>
</tbody>
</table>

1 For descriptions of content for cognitive, procedural and affective episodes, please see appendix A. Off task episodes were not formulated.