



Trends and issues of regulative support use during inquiry learning: Patterns from three studies

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ABSTRACT

This paper looks across three experimental studies that examined supports designed to assist high-school students (age 15–19) with cognitive regulation of their physics inquiry learning efforts in a technology-enhanced learning environment called Co-Lab. Cognitive regulation involves the recursive processes of planning, monitoring, and evaluation during learning, and is generally thought to enhance learning gains for students. The research synthesis described in this paper examined the usage effects of a support tool called the process coordinator (PC) on learning outcomes. This tool incorporated goal-lists, hints, prompts, cues, and templates to support the cognitive regulation skills of students during a fluid dynamics task. Students were asked to produce two learning outcomes of their investigations: system dynamics models and lab reports. Results from the three studies indicated trends in frequent use of the PC for planning activities, but low usage for monitoring and evaluation. Correlational analysis revealed two trends with regard to how these regulative activities impacted learning outcomes. First, consistent positive correlations were apparent between regulative activities and lab report scores of students and second, consistent negative correlations between the use of supports and model quality scores. Trends with regard to how task complexity, time, and student prior experience impacted these findings are also presented with suggestions for future research.

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1. Introduction

Considerable amounts of research have focused on the design of software tools for technology-enhanced learning environments (Aleven & Koedinger, 2002; Bera & Liu, 2006; Clarebout & Elen, 2006). Software tools in a learning environment can be designed for a variety of purposes. They can assist students with conduction of a domain activity, as with data analysis tools (tables and graphs) for a science experiment, or with domain manipulation such as a simulation. They can assist students in creating a domain representation, such as the provision of a concept-map (see also Zumbach, 2009), modeling tool, or animation. Software tools can also fulfill a regulative function, providing students with a vehicle to plan, monitor, and evaluate their learning. Examples of this type of support include goal lists, note-taking facilities, and system generated prompts, which aid students in the creation of self-explanations (Chi, Bassok, Lewis, Reimann, & Glaser, 1989). The research presented in this paper focuses on this sort of regulative support.

Usage of regulative support within technology-enhanced learning environments has successfully impacted learning in research studies (Kramarski & Gutman, 2006; Manlove, Lazonder, & de Jong, 2006; Veenman, Elshout, & Busato, 1994). Their successfulness in

fostering learning is due to their emphasis on what Pintrich (2000) calls cognitive regulation: a process of directing learning based on feedback loops generated by goals, monitoring of comprehension or progress, and evaluation of outcomes. This recursive process is based on theories of self-regulation (Butler & Winne, 1995; Schraw, 1998; Zimmerman, 2001) which describe how students direct their learning utilizing self-knowledge of declarative and procedural domain information for more successful learning (Ertmer & Newby, 1996).

Regulatory supports assist students to plan, monitor, and evaluate via prompts and other mediation mechanisms, which are thought to aid in student elaboration and reflection of their learning. The research of White and Frederiksen (1998) found, for example, positive impacts from reflective assessments aimed toward helping students monitor their learning and understanding of science content in their Thinker Tools curricula. Veenman et al. (1994) and Zhang, Chen, Sun, and Reid (2004) supported students' regulation with support devices designed to promote reflective thoughts about learning goals, comprehension, progress, and evaluation of learning while engaged in technology-enhanced learning environments. Both of these studies found that students provided with such support outperformed students who did not have access to it.

The success of these studies may be conditional on the fact that the students were exposed to embedded regulatory supports.

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Clarebout and Elen (2006) distinguish embedded support from non-embedded support in the sense that the former is not based on student initiative for their use (they are simply forced to use it), whereas the latter does rely on student choice. Given their optional nature, it is unclear whether non-embedded supports are also fruitful in helping students to learn content. Non-embedded supports may be beneficial to learning in that they allow students to choose when and where to apply self-regulation strategies. This freedom can offset an often perceived cognitive burden embedded support creates (Lan, 2005). Non-embedded support comes, however, with a somewhat dangerous tacit assumption. Designers of this type of regulative support seem to believe that simply providing students with the tool means they will use it, and use it in a manner that will help them achieve their learning goals.

The relationships between students' non-embedded regulative support use on the one hand, and their regulative activities and learning outcomes on the other were central to the research of Manlove et al. (2006), Manlove, Lazonder, and de Jong (2007), Manlove, Lazonder, and de Jong (in press). Three studies were conducted in a technology-enhanced inquiry learning environment known as Co-Lab (van Joolingen, de Jong, Lazonder, Savelsbergh, & Manlove, 2005), and addressed the usage and effects of a regulative support device called the process coordinator (PC). The first two studies (Manlove et al., 2007, in press; Manlove et al., 2006) revolved around differences in learning outcomes with a full PC versus a PC from which all regulative directions were removed. In general, these studies showed that high-school students learning in small groups often do not take full advantage of the support offered by the PC. That is, they often used the regulative supports to gain an understanding of the task through the provision of goals, but once this understanding was reached they tended to abandon the supports which were meant to assist in monitoring. The research of Bera and Liu (2006) and Oliver and Hannafin (2000) expressed similar concerns with regard to students generally neglecting available supports.

This outcome lead to questions about the role collaboration played in the regulative support use. While collaboration is thought to promote co-construction of plans, monitoring, and evaluation behavior (Chi, Leeuw, Chiu, & LaVancher, 1994; Chi et al., 1989; Lazonder, 2005; Teasley, 1995) it was wondered if the presence or absence of a peer negatively impacted regulative support use specifically in that groups would rely on each other rather than on the support devices provided. The third study depicted in this paper (Manlove et al., in press), therefore, explored whether pairs used the PC less than single students. Although, this result was not borne out to a significant degree, a strong general trend was apparent of single students using supports more than pairs.

In order to explore why regulative support use expectations were not met in the Manlove et al. (2006), Manlove et al. (2007, Manlove et al. (in press), it is helpful to examine trends in how the regulative supports provided were used for planning, monitoring, and evaluation activities and how this usage impacted learning outcomes. In addition, an examination of how other factors and tools in the learning environment played a role in regulative support use might shed light on the improvements for regulatory support design. Factors addressed include task complexity and time, student prior achievement and collaborative versus individual use of supports.

Prior to presenting empirical evidence of regulative support effects found in these studies, an overview of the studies and the regulative supports is presented in Section 2. Section 3 presents effectual evidence with regard to regulative supports found in this research, seen in two main forms throughout the three studies: regulative activities and learning outcomes. Section 4 presents a discussion of trends from this research and how factors such as task complexity and time and student prior experience may have impacted the results.

2. Overview of the studies' setup and methods

Three studies were conducted to investigate the impact of regulative support use. In order to contextualize the regulative support features, a brief overview of the studies is presented first along with the learning task and environment. Study 1 examined the impact of a "full" version of a regulative tool (the PC+) against a version where supports were removed (PC-). Study 2 compared the same versions of the PC (but with an improved interface) and the addition in the PC+ of supports to increase monitoring activity; no changes were made to the PC-. Results from these studies prompted the investigation within study 3 of whether use of the PC+ differed when used by collaborative groups or by individuals.

2.1. Participants

In study 1, 61 high-school students (aged 16–18) were grouped in 19 triads and 2 dyads based on track ability matching, with one student from a science track and two non-science tracked students per group. Groups collaborated online via a chat tool in the Co-Lab environment. Random allocation of student groups into the conditions resulted in 10 PC+ and 11 PC- groups.

In study 2, 70 high-school students (aged 16–18) majoring in science worked in dyads. In contrast to study 1, students collaborated face-to-face in front of one computer. Students were allocated into medium-range mixed ability dyads based on teacher-supplied ranks. Twenty dyads received the PC+ that contained the regulative guidelines described below; dyads in the PC- condition ($n = 15$) worked with an "empty" PC from which the regulative guidelines were removed.

In study 3, 42 high-school students (aged 16–18) majoring in science worked either individually ($n = 18$) or in Pairs ($n = 12$) within Co-Lab. Students in 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. Singles performed the same task individually and served as control group.

2.2. Learning environment and task

Students in all three studies worked on a fluid dynamics task that invited them to inquire about factors that influence the time it takes to empty a water tank. This task was performed within Co-Lab, a scientific inquiry learning environment that provided students with a simulation of a water tank, and a data and graph tool with which they could view results from their simulation runs. Students were invited to express acquired understanding in a runnable, system dynamics model and a lab report. When collaborating, group members could discuss their inquiry with a synchronized chat in study 1; this feature was removed from the environments in subsequent studies since collaboration occurred face-to-face in front of one computer. This modification was deemed necessary because learning discourse analysis from student chat logs in study 1 (not reported here) suggested that the quality of the students' interactions would improve if collaboration occurred face-to-face (cf. Sins, van Joolingen, Savelsbergh, & van Hout-Wolters, submitted for publication). To illustrate, about half of the regulative utterances in the groups' chat discussion pertained to regulation of group members' location in the learning environment, requests for what they were doing, and confusion about group member activities – all of which was caused by a lack of social presence. Beyond these tools, help files gave students assistance with tool operation and domain content to all students. These help files were available in a help file viewer and covered topics such as the operation of the model editor, modeling terminology, and assistance with the formula for Torricelli's law. A full

description of the Co-Lab environment can be found in van Joolingen et al. (2005).

2.3. Regulative supports

The design of the PC focused on supporting cognitive regulation (Pintrich, 2000). 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). Three activities are generally thought to be essential for cognitive regulation: planning, monitoring, and evaluation (Butler & Winne, 1995; Schraw, 1998; Zimmerman, 2000). Where planning consists of goal setting activities, monitoring involves in process checks of both comprehension and task progress. Evaluation was distinguished within these studies as being reflection on action (Schön, 1991), where students take a step back from their work to evaluate both learning products and learning processes. Table 1 gives an overview of the regulative supports coupled to their regulative processes for all three studies.

Regulative support for planning, monitoring, and evaluative activities was provided in the PC+. As mentioned above, some improvements were made between the first and subsequent studies, leading to two different versions of this tool (see Figs. 1 and 2).

Table 1

Overview of the regulative supports in the three studies

Regulative process	Study 1	Studies 2 and 3
Planning	Collapsible goal tree Hints	Inquiry cycle Sub-goals
Monitoring	Note feature	Note feature Question prompts Timed cues Hints
Evaluation	Lab report template	Lab report template

The “taking off point” for use of the PC+ was to select a goal or sub-goal. In study 1, this consisted of a goal tree hierarchy which could be expanded and reduced to see sub-goals under overarching top goals (see Fig. 1). In studies 2 and 3, this was modified to present top level goals in a visual cycle format (see Fig. 2). This decision was made given results from study 1 and an exploratory study (Manlove & Lazonder, 2004), which showed that students followed processes linearly rather than in the cyclical, iterative fashion that is typical of a scientific inquiry. Clicking on one of the steps in the cycle displayed the list of sub-goals. Together these regulative supports were meant to support planning activities in that students

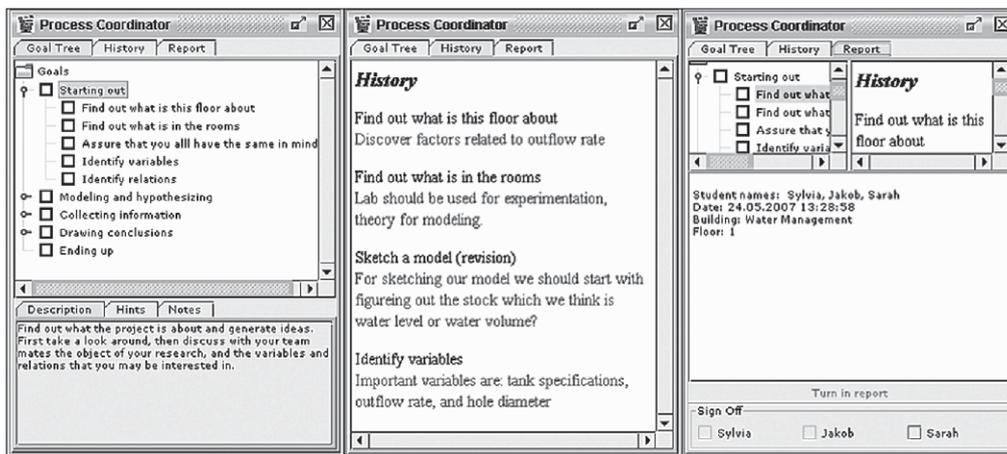


Fig. 1. PC+ from study 1. Tabbed views (from left) show the goal tree, history, and report.

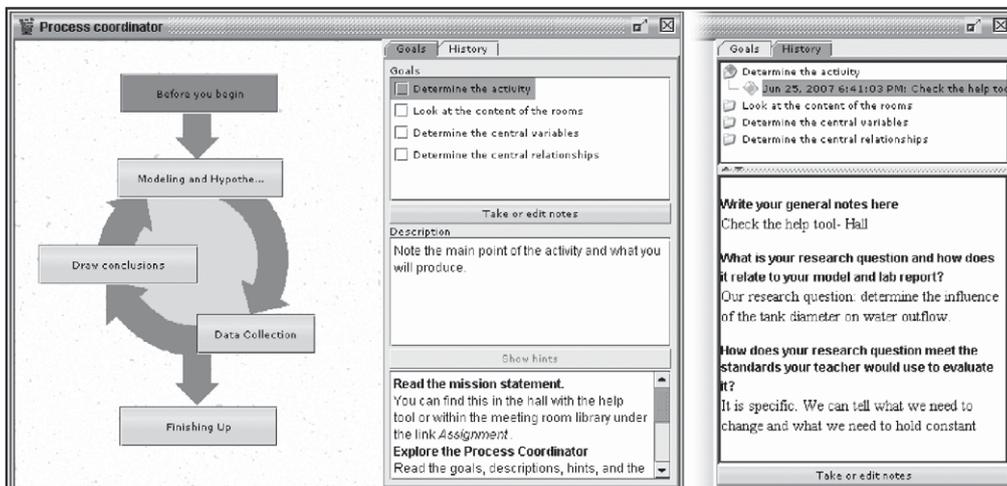


Fig. 2. Goal tree view (left) and history view (right) of the PC+ used in study 2 and 3.

could choose an overarching process and see sub-goals as a means of generating a strategy for completion of the activity. Once a goal was selected students could view a goal or sub-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-taking feature. Notes were appended to goals, therefore in order to create a note, students first had to select a goal and a sub-goal. In studies 2 and 3, the monitoring support was expanded to include question prompts within a note template, and timed “pop-up” cues reminding students to take a note at specific stages of their science investigations. The question prompts were designed to elicit self-explanations (Chi et al., 1989; Davis, 2000; Davis, 2003; Lin & Lehman, 1999; see also Horz, Winter, & Fries, 2009) and reason justification (Lin & Lehman, 1999) in notes. Self-explanation questions (e.g., “Which variables are you most and least sure have an effect on the time it takes to empty a pool?”) were designed to help students monitor their comprehension. Reason justification prompts (e.g., “For the variables you are most sure have an effect, why do you think so?”) were designed to help students determine evidence of their comprehension. Each note template contained one of each of these types of questions and an area for general notes. The timed pop-up cues appeared when students ended an inquiry phase, indicated in Co-Lab by a virtual room change, or appeared every 10 min if a note was not taken or a room change was not made. The cues were suggestive only in that students were not forced to take a note and could click the cues away. Additionally, the PC+ contained a process view, called the “history”, which gave students a sequential record of their notes and allowed the contents to be copied directly to their reports. This was meant to assist students in tracking their understanding during their investigations.

Evaluation was supported in the PC+ with the provision of a lab report template, which gave section headers and content suggestions students could use to evaluate their inquiry work. In study 1, this template was available directly in the PC+'s report editor feature. Due to technical problems, a separate report editor was used in studies 2 and 3 with the template housed in a help file.

The PC– control conditions in studies 1 and 2 were not provided with the regulative directions described above (i.e., preset goals, descriptions, and hints). They could, however, create their own goals and notes which could be copied to their reports so as to maintain the PC's functionality without giving any regulative guidance at all. Completely removing the possibility for goal setting and note taking was considered unfair because PC– groups would then have no place at all to record their plans, intermediate results and so on (note taking on paper was not allowed). In addition, the PC– groups were not provided with a report template. Study 3 did not utilize PC– as it investigated the effects of collaboration on regulative support use. Therefore, both Pairs and Singles had access to all the regulative supports of the PC+ found in study 2.

2.4. Procedure

Prior to beginning the experimental task, participants in all three studies attended a 20 min experimenter-led introduction to Co-Lab and its tools, including the PC. Given the different versions of the PC, students were referred to the help files provided in their version of the environment for specific operational questions. This introduction was followed by an individual 40 min hands-on tutorial on the creation of system dynamics models. Students were then asked to be seated in their group, or in the case of study 3 individual, seating assignments to begin the learning task. In study 1, time allotted for the learning task was two hours. As this proved insufficient for students to produce full models and lab reports,

students in subsequent studies were allowed three hours to complete their inquiry.

2.5. Coding and scoring

Data analysis focused on regulative activities with the PC, and learning outcomes. Data was taken from (1) frequencies of student PC actions (i.e., clicking a button, tab, or field on the PC) generated from log files, (2) model quality scores generated from a coding framework based on a target model, and (3) a lab report rubric which assessed student write ups of their investigations.

PC actions in all three studies were associated with specific regulative processes. Although minor discrepancies in this classification occurred due to the formative nature of the experiments (i.e., subsequent experiments built on the results and insights gleaned from prior experiments with the aim of improving regulative supports and the environment) actions were generally classified as follows. Planning was indicated by (1) goal or sub-goal viewing, (2) goal or sub-goal description viewing, and (3) adding a goal (in Studies 2 and 3 adding a goal was no longer possible in the PC+ version). Monitoring was associated with (1) adding notes to goals, (2) viewing notes, and (3) viewing help files (in studies 2 and 3). Viewing hints was also counted in the PC+ condition as a monitoring act in studies 2 and 3. This action was considered as a planning action in study 1, however, it shifted theoretically to a monitoring activity in studies 2 and 3. The reason for this shift was that hints were originally meant to supplement the overall strategies given by the goal lists. In studies 2 and 3, changes to the content of the hints referred students to relevant help files. Help file viewing is considered a monitoring act in that “help-seeking” is designated as a fix to a comprehension failure. Evaluation was assessed when students created a report by clicking the report tab in study 1, or use and time of the report editor in studies 2 and 3.

Learning outcomes were assessed from the students' model and lab reports. Student models conveyed a student's conceptual knowledge of the domain and their understanding of the physics problems. As such a model represents both correct understanding of individual variables and the relationships specified between the variables. Assessment of student models, therefore, came from examining the number of correctly specified variables and relationships based on a target model (see Fig. 3). One point was awarded each for correct variable name and type. Relationships were awarded one point for correct linkage and up to two points were given if the relationship was correct in direction and specification. Students had the option in Co-Lab to create qualitative (i.e., simple linear designations for relationships as shown in Fig. 3) or quantitative specifications (i.e., mathematical equations) for variable relationships. Either was acceptable. The maximum model quality score was 26. Inter-rater reliability estimates (Cohen's κ)

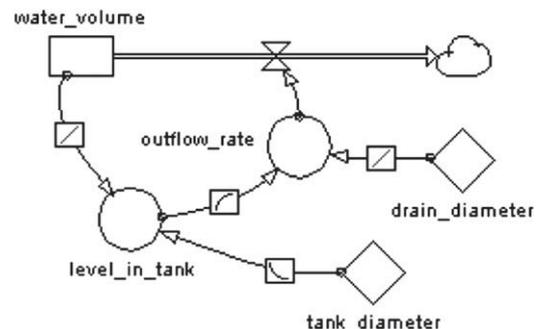


Fig. 3. Reference model for the experimental task.

for variables and relations were .90 and 1.00 in study 1, and .95 and .91, respectively, for studies 2 and 3. Deviating scores were discussed until mutual agreement was reached.

A rubric was developed from the report template provided to students in the PC+ conditions. This rubric assessed report structure for presence of sections found in the template. One point was awarded for each included section with a total of five points possible. Report content was evaluated based on the extent to which students addressed topics of evaluation described in the template. Examples include “state your research question”, “list your hypothesis”, and “describe the pros and cons of your working method”. A total of 11 topics were designated. All reports were scored by two raters in study 2, where inter-rater agreement reached 85.14% for report structure and 86.49% for report content. (Percentage agreement was used because codings could be mutually dependent.) Twenty percent of the total lab reports were scored by a second rater for content in study 3 with inter-rater agreement reaching 75.77%. Subsequent deviations were discussed until mutual agreement was reached. Due to time constraints in study 1, lab report scores were analyzed from studies 2 and 3 only.

2.6. Data analysis

Study 1 data analysis focused on between-group differences in learning outcomes and regulative activities. Given the relatively small sample size and the skewness of some distributions, between-group differences were analyzed by non-parametric Mann–Whitney U tests.

Study 2 data analysis focused on between-group differences in regulative activities and learning outcomes. 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. To ensure that observed differences in learning outcomes were attributed solely to the use of regulative scaffolds, the dyads’ achievement level (indicated by the teacher-assigned level of the highest achieving group member) was used as an additional factor.

Study 3 used a between-subjects design with collaboration (Pair, Single) as the independent variable and regulative support use and learning outcomes as dependent variables. One pair was equal to one case in the analysis. 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. To ensure that these differences were not attributed simply to a higher achieving student within the dyads, analyses for learning outcomes used achievement level (indicated by the teacher-assigned level of the highest achieving group member (Pairs) or individual student (Single)) as a covariate.

In all studies, correlational analyses were performed to examine the relationships between regulative support use for regulative activities and learning outcomes. Detailed regulative support use data was not available in study 1, so the regulative support use analyses from studies 2 and 3 were used to contextualize the overall patterns.

3. Results

3.1. Regulative activities

Table 2 presents the composite frequency scores from the three studies for planning, monitoring, and evaluation activities with the PC by condition. Except for Singles in study 3, composite scores represent the sum of actions made by all group members. With re-

Table 2
Summary of regulative activities

	Planning		Monitoring		Evaluation	
	M	SD	M	SD	M	SD
<i>Study 1^a</i>						
PC+	96.88	31.82	18.11	15.96	0.00	0.00
PC–	21.89	9.49	17.00	15.13	0.22	0.44
<i>Study 2^b</i>						
PC+	27.70	19.57	30.15	22.46	16.75	13.11
PC–	3.33	4.3	29.07	9.16	10.80	6.48
<i>Study 3^b</i>						
Pairs	56.25	21.82	47.83	21.03	22.41	12.47
Singles	62.89	22.94	61.42	25.25	25.11	11.02

^a Planning composite consists of adding and viewing goals, monitoring consists of adding and viewing notes, and marking goals complete. Evaluation looked at number of times the report editor was opened.

^b Planning composite consists of viewing goals. Monitoring consists of PC actions for adding notes, viewing notes, viewing hints (in study 2, the PC+ condition only had access to hints, in study 3 both conditions could access hints), and viewing help files. Evaluation consists of use of the report editor activation.

gard to planning, PC+ groups in studies 1 and 2 performed significantly more PC actions associated with this regulative activity than PC– groups did ($Z = 3.26$, $p < .001$, $d = .05$, respectively $t(20.31) = 5.77$, $p < .01$, $d = 1.68$). Study 3 indicated that although Singles used the PC slightly more often than Pairs for planning, this difference was not statistically significant ($F(1,28) = .65$, $p = .43$).

Fine-grained analyses of the data obtained in study 2 were performed to contextualize the above findings. In absence of regulative directions PC– groups 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. PC+ dyads viewed goals nine times more often than PC– dyads ($t(21.48) = 5.39$, $p < .01$, $d = 1.72$). This result is not surprising given that PC– groups created their own goals and thus had less to view, in addition it may be that PC– groups remembered their own goals since they had to come up with their own and as such did not need to rely on the PC for keeping track as much as PC+ groups.

Although, monitoring shows some increased scores from planning in Table 2, this is a function of the composite of activities (more activities were related to monitoring) rather than a reflection of actual monitoring, which becomes more apparent in the following analysis. Monitoring actions did not differ as a function of regulative support (study 1: $Z = .263$, $p = .80$; study 2: $t(26.59) = .20$, $p < .85$). Apparently, students in the PC+ condition used the PC for monitoring purposes just as often as their PC– counterparts did. Collaboration also did not impact the use of regulative supports for monitoring. Single students in study 3 engaged slightly more often in monitoring activities than Pairs did, but again not to a statistically significant degree ($F(1,29) = 2.41$, $p = .13$).

A more detailed look at regulative support use for monitoring in study 2 showed that the PC– group relied on help files which listed domain and modeling information significantly more than their PC+ counterparts ($F(1,33) = 10.92$, $p = .01$, $d = 0.55$). In fact PC– students looked at help files almost twice as much across the experimental sessions. Means were 21.20 (SD = 9.17) and 10.60 (SD = 9.56) for PC– and PC+ groups, respectively. The high standard deviations in evidence suggest, however, that this result varies across groups in the PC+ condition. In fact 5 of the 20 PC+ groups viewed help files more than 15 times, the range for these five groups was between 19 and 35 help file views, whereas the remaining 15 groups had between 1 and 15 help file views. PC+

groups who also had access to hints looked at them approximately four times across the experimental sessions. Whereas in the case of study 3, Singles averaged 23.74 help file views ($SD = 11.97$) which was slightly more than Pairs 18.75 ($SD = 12.14$), this result was statistically insignificant ($F(1,29) = 1.26, p = .27$). Note-taking frequencies indicated that although the PC+ groups ($M = 10.25, SD = 14.84$) showed intent to take notes by clicking the “take note” button more than twice as often as their PC– counterparts ($M = 4.07, SD = 2.99$), this difference was not statistically significant, $t(21.03) = 1.82, p < .10$. The intent to take a notes of single students ($M = 21.17, SD = 12.51$) showed slightly higher frequencies than Pairs ($M = 16.00, SD = 10.97$) but this was not statistically significant ($F(1,29) = 1.56, p = .22$).

Cues and note-template prompts had very little effect. In study 2, 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 (as opposed to discarded notes) by students were very low (PC+: $M = 4.35, SD = 6.05$, PC–: $M = 2.53, SD = 3.46$). In study 3, 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 both Pairs and Singles who saved on average nine notes across the five sessions (Pairs: $M = 9.93, SD = 6.51$, Singles: $M = 9.95, SD = 5.44, F(1,28) = .14, p = .71$). Singles responded only slightly more to general (56%), comprehension monitoring (58%), and reason justification (34%) prompts than their collaborative counterparts at 54%, 50%, and 33%, respectively. These differences were not found to be significant ($F(3,25) = .41, p = .75$).

Central to evaluation activities was report writing and use of the report editor. As none of the groups reached a point in their inquiry in study 1, where it would have been appropriate to evaluate their work, evaluation activities were excluded from this analysis. Studies 2 and 3 data revealed that PC actions associated with evaluating were few and comparable across conditions. As shown in Table 2, there were only slight differences between the conditions in terms of activating the report editor and these differences were not statistically significant (study 2: $F(1,33) = 2.60, p = .12$; study 3: $F(1,29) = .47, p = .50$). Nor was the comparison between the conditions in these studies on report editor use time (study 2: $F(1,26) = .01, p = .92$; study 3: $F(1,29) = 2.46, p = .13$). Mean times in minutes for report editor use were 28.54 ($SD = 10.23$) for the PC+ groups and 29.03 ($SD = 15.59$) for PC– groups. This amount of time was consistent with pair and single report editor times (Pairs: $M = 30.86, SD = 9.93$, Singles: $M = 37.86, SD = 13.27$). The template that assisted the groups in these studies showed that it was consulted by 16 out of 20 PC+ dyads. The majority of these dyads viewed the template once or twice during the writing process. Both Pairs and Singles viewed the report template at least one time (Pairs: $M = 1.92, SD = .10$, Singles: $M = 1.79, SD = 1.13$), with no significant differences found ($F(1,29) = .10, p = .75$).

3.2. Learning outcomes

Learning outcomes were indicated by the quality of the groups’ final models and their lab report scores. Table 3 lists the learning outcomes from all the studies. Turning first to model quality, PC+ students in study 1 evidenced better models than their PC– counterparts ($Z = -2.07, p < .05, d = 1.43$), but this trend reversed in study 2 with PC– groups showing significantly higher model quality scores than their PC+ counterparts ($F(1,31) = 9.98, p < .01, d = 1.26$). In study 3, Pairs outperformed Singles ($F(1,27) = 9.07, p < .01, d = 1.09$) with regard to their models. Students’ achieve-

Table 3
Summary of learning outcomes

	Model quality ^a		Lab report			
	M	SD	Report structure ^b		Report content ^c	
			M	SD	M	SD
<i>Study 1</i>						
PC+	9.38	4.03	–	–	–	–
PC–	5.78	3.77	–	–	–	–
<i>Study 2</i>						
PC+	11.00	6.05	4.33	1.64	7.40	1.64
PC–	18.40	5.65	3.45	.69	4.45	1.44
<i>Study 3</i>						
Pairs	21.00	3.83	4.33	0.88	14.00	3.05
Singles	17.28	2.94	4.06	1.21	10.61	4.91

^a Maximum score = 26.

^b Maximum score = 5.

^c Maximum score = 28.

ment level was also taken into account in studies 2 and 3 to ensure that effects could not be attributed solely to student abilities in the groups. Achievement level had no main effect on model quality in either of these studies (study 2: $F(1,31) = .40, p = .53$; study 3: $F(1,27) = .41, p = .53$). In study 2, however, the condition \times achievement interaction proved statistically significant ($F(1,31) = 6.76, p < .05$); post hoc analyses showed that 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.

Due to time constraints, lab report scores were only available from studies 2 and 3. As shown in Table 3, PC+ students in study 2 produced significantly better structured reports than PC– groups ($F(1,22) = 9.57, p < .01, d = 1.49$). Achievement level had no effect on this measure ($F(1,22) = .29, p = .60$); the condition \times achievement interaction was not significant either ($F(1,22) = .147, p = .24$). PC+ students also gave more elaborate accounts in their reports than PC– students ($F(1,24) = 22.66, p < .01, d = 1.74$). There was again no significant main effect of achievement level ($F(1,22) = .05, p = .83$) and no significant interaction ($F(1,22) = .01, p = .92$). In study 3, Pairs and Singles had comparable report structures ($F(1,27) = .35, p = .56$) with achievement level showing no impact on this outcome ($F(1,27) = 1.73, p = .20$). Achievement did impact report content however ($F(1,27) = 8.35, p < .01, d = .82$). Correcting for this in the analysis revealed that Pairs gave more elaborate accounts of their work than Singles ($F(1,27) = 4.68, p < .05, d = 0.83$).

3.3. Correlations

Correlational analyses were performed to reveal how learning outcomes were related to regulative activities. In study 1 model quality was not associated significantly with PC use for planning and monitoring, this was also found to be the case in study 3. Of note however is the fact that analysis from these studies revealed consistency in the negative direction of the correlations between model quality and goal-viewing. Studies 1 and 3 point to the idea that the more students viewed goals, the lower their model quality scores tended to be. This finding was borne out significantly in study 2, where higher model quality scores were significantly associated with lower instances of goal viewing and note taking ($r = -.54, p < .01, r = -.40, p < .05$). The correlation between model quality and help file 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 lab report structure with significant positive correlations for viewing goals ($r = .62, p < .01$), taking notes ($r = .54, p < .01$) and viewing notes ($r = .58, p < .01$). Report content positively correlated with

goal viewing ($r = .51, p < .01$) and viewing notes ($r = .40, p < .05$). In contrast, help file viewing negatively impacted report structure ($r = -.59, p < .01$).

4. Discussion

In general, the studies reported here show several trends with regard to how regulative supports were used and how they impacted learning outcomes. The first trend relates to how process goals such as the goal hierarchy and inquiry cycles support students in planning activities. In all of the studies, the PC+ was effective in promoting goal viewing; it was in fact the most used feature of the PC+. Collaboration did not impact this result showing that students who work together rely on process directions just as much as students who work alone. PC– groups who had to set their own goals did so sparingly and as such had little to view, therefore, the impact of the PC+ is not surprising. Another possibility is that PC– groups remembered their goals since they had to come up with their own and as such did not need to rely on the PC for keeping track as much as PC+ groups. The high usage of the PC+ for goal viewing however does suggest that the non-embedded support which offers students a process for completing an inquiry task is found to be beneficial and will be used by students especially perhaps in technology-enhanced learning environments which ask students to perform complex and unfamiliar tasks such as modeling.

The second trend relates to the relatively low instances of monitoring and the lack of statistical significance for support effects found in these studies. Study 1 proved that just supplying students with a note editor in no way assured effective note-taking. This finding is consistent with the research of Bera and Liu (2006), and Greene and Land (2000), which showed non-adequate use of embedded support devices. Subsequent studies sought to increase monitoring activity and aimed also for sustained monitoring efforts throughout the inquiry process with the use of timed cues and note template prompts. Results of studies 2 and 3 showed that these supports failed to produce the anticipated effects. Yet this finding does not necessarily disqualify the efficacy of cues and prompts for monitoring (cf. Chi et al., 1994; Davis, 2000; Davis, 2003). The studies reported in this paper started from the implicit assumption 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; perhaps a few acts of monitoring are as beneficial to learning as a large amount of planning activities. This in turn raises the issue of how much externalization of monitoring in the form of notes 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.

This leads to another insight with regard to the monitoring supports. From a design perspective, the monitoring support such as those utilized may have been too “distant” from activity conduction. In order for students to utilize the monitoring facilities they had to stop task conduction, open a tool, select a goal, and then attend to comprehension and progress checks. It is possible that students felt that this took too much time and effort away from the learning task. Future research could examine if monitoring support is more effective if anchored within the task activities, rather than in a regulative tool set apart from student work. Another possibility is that such anchored supports might be more effective if they are an obliged part of the activity (i.e., embedded support; Clarebout & Elen, 2006) rather than solely relying on student initiative and choice for their use.

The lab report template showed a consistently positive effect for evaluative work although in study 3 both groups had access to it. PC+ students evidenced better structured and more elaborate write ups of their scientific investigations than their PC– counter-

parts in study 2. PC– students in contrast had to rely on their own knowledge of what to include in lab reports and created less coherent views of their scientific investigations. In study 3, where Pairs evidenced the same findings over Singles, the presence of a peer was shown to enhance this result. This indicates the benefits of collaborative work for evaluation: presence of a peer may assist student discussions of the template sections which lead 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.

A third trend from the findings in this research concerns the match between support form and learning outcomes. Salomon, Perkins, and Globerson (1991) refer to this match as the effects of technology on learning outcomes where outcomes are controlled by the supports provided. Evidence of this trend comes from two consistent correlational trends apparent across the studies. It seems that the more students used the PC 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). In contrast, consulting the PC's goal lists positively correlated with lab report scores. The PC gives process support, the content of which was often a one-to-one match with the phases of scientific reasoning (inquiry cycle). These phases in turn matched headings in the lab report template. Thus, the goal lists may have reminded and attended students to content for their reports, but could have lacked a degree of specificity needed to support modeling work. Specific modeling domain information coupled with information about use of the model editor was offered in the help files. The fact that the use of these files significantly and positively correlated with the model quality scores in study 2 suggests that this information allowed students to “fill in” and supplement the general strategy given in the PC. 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.

The results of the research conducted point to two important factors to take into account when designing regulative support. The first is student's prior experience and knowledge. All participants were in the last years of high-school science and 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. The process support found within the PC goal viewing 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. The process could be easily integrated with prior knowledge of what they understood to be the scientific method of inquiry. Contrasted with modeling, however, the regulative supports perhaps were not specific enough. Students had little experience in this area, and might, therefore, have lacked the knowledge base required to benefit from the general directions provided to them by the regulative supports.

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 (Schraw, 1998). 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. Such pretraining or off loading might be beneficial to student-centered learning activities found in technology-enhanced learning (Moreno & Mayer, 1999).

Naturally, students' prior achievement in science is also a factor in the use of regulative support. This is nicely illustrated within study 2 where low-achieving dyads in the PC- condition were shown to have created better models than their supported counterparts due to increased 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 as it reduces task complexity and cognitive load during the learning process (van Merriënboer, Kirschner, & Kester, 2003).

Both of the above points with regard to student prior experience and achievement in science are impacted by learning task complexity and time. Modeling is 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 supports, 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 support use for monitoring suggests students did feel burdened by trying to regulate and understand domain content and the complexity of modeling.

Research with regard to affordance of student ability to regulate their cognition during learning runs the gamut from environment directive support (e.g., Veenman et al., 1994; Zhang et al., 2004) to open-ended unguided student control. The studies depicted here indicated that a fine balance is required between learning outcome expectations, their match to regulative supports, and expectations of the use of regulative supports in the face of task complexity, time and student prior experience. While students in these studies seemed to welcome the planning support in the face of a complex and unfamiliar task, the monitoring support seemed to be more sensitive to waning student initiative in the same circumstances. Expectations of usage of regulative support then need to be examined in future research with regard to task characteristics, student experience and the match they make to learning outcomes. The role of other supports such as presence of a peer also needs to be taken into consideration at a more detailed level than was shown in study 3 depicted here. Taking these factors into consideration in the design and research regulative supports may aid in optimizing student goal setting, checking understanding and evaluation of their efforts for the betterment of learning.

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