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Profiling Learners' Co-Regulation Patterns with a Pedagogical Agent in an Intelligent Tutoring System for Learning About Human Biology[1]

Jason M. Harley, Michelle Taub, François Bouchet, Joan Henchey, & Roger Azevedo

McGill University, Laboratory for the Study of Metacognition and Advanced Learning Technologies, Montréal, Canada

jason.harley@mail.mcgill.ca

Abstract. Examining co-regulated learning between human and artificial pedagogical agents is extremely important and has recently led to a surge in research on the conceptual, theoretical, methodological, analytical, and educational issues behind other-regulated learning. This study used a novel coding framework to examine Co-Regulated Learning (CoRL) between learners and pedagogical agents (PAs) during the sub-goal setting phase with MetaTutor, an adaptive, intelligent, hypermedia learning environment. This paper highlights the importance of examining tutorial feedback using a granular research lens, which we used to examine differences in the interactions (and learners' subsequent learning sessions) between learners and a PA both within and between MetaTutor's two pedagogical agent scaffolding conditions: prompt and feedback (PF) and control (C). The results demonstrate that co-regulated learning interactions can take place between learners and PAs and that they can lead to increased use of SRL strategies (judgments of learning, content evaluation), a more effective use (e.g., selection of more relevant pages related to one's goals), as well as higher proportional learning gains than less collaborative learner-PA interactions. Future work will examine the relationship between different learner-PA interactions and emotions as well as additional co-regulated learning interactions between PAs and learners.

Keywords. Computer-based learning environments; tutoring; self-regulated learning; co-regulated learning; coding scheme; process and product data; computers and learning; self-directed learning.

Objectives and Theoretical Framework

A primary focus of research on learning with computer-based learning environments (CBLEs) has examined the process of self-regulated learning (SRL) (e.g., see Azevedo & Aleven, in press). Researchers have paid little attention, however, to examining the role of human tutors (HT; Azevedo & Hadwin, 2005; Graesser & McNamara, 2010) or pedagogical agents[2] (PA) in helping learners to develop their SRL skills (Hadwin, Jarvela, & Miller, 2011). There are a variety of terms to describe variants of other-regulated learning, including externally regulated learning (ERL; Azevedo et al., 2012), socially-shared regulated learning (SSRL; Jarvenoja & Jarvela, 2009; Jarvela, Volet, & Jarvenoja, 2010), and co-regulated learning (CoRL) (Hadwin et al., 2005). Using Hadwin and colleagues' (2011) framework, we believe that CoRL is the most appropriate process to

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[2] PAs are embodied, virtual tutorial agents that inhabit intelligent tutoring systems (ITSs) and use artificial intelligence (AI) to respond and adapt to learners as they interact with the computer-based learning environment.

describe the interaction between learners and HTs or PAs because there is a distribution of expertise between them that can be used to influence (i.e., mediate) the internalization and effective use of SRL skills in order to facilitate learning. Furthermore, in analyzing tutor-learner interactions, the emphasis is placed upon examining the role that each agent plays in supporting and developing SRL.

Saab et al. (2011), Janssen et al. (2010), and Lajoie and Lu (2010) have all recently assessed CoRL in different educational contexts. All three studies used a coding scheme to assess the dialogues that stemmed from the interactions between the students, which is a critical aspect of analysis given the importance of communication for effective collaboration and successful learning. In all of the studies, the importance of social regulation was emphasized, which implies that in order for co-regulated learning to be successful, learners must pay special attention to the interactions between all members involved in learning.

In addition to expanding and extending the state of the art with further empirical research examining CoRL, it is especially critical to extend our understanding of CoRL to interactions between humans and PAs, which is the overall goal of this study. An in-depth analysis of these interactions is needed, in particular, to understand the qualitative and quantitative issues regarding self- and other-regulated processes to support learning. Furthermore, such work will provide valuable information that will help education and AI researchers evaluate best practices for PA's scaffolding designed to foster SRL strategy use and improve learning (e.g., Sabourin, Shores, Mott, & Lester, 2012; Segedy, Kinnebrew, & Biswas, 2013; Tan & Biswas, 2006). Currently, no (published) research examining CoRL with PAs and learners has been conducted outside of our program of research (Harley, Taub, Bouchet, & Azevedo, 2012). Therefore, this study stands to make significant theoretical, analytical, and educational contributions to the emerging field of CoRL by investigating whether such interactions can be identified between PAs and learners.

Specifically, this study has two major goals: (1) to develop a coding scheme to classify learners' interactions with the PA during the sub goal setting phase of learners' interactions with MetaTutor (an adaptive, intelligent, hypermedia learning environment; Azevedo et al., 2010, 2012b, in press) into different types of co-regulated learning human-PA profiles (CoRL-HPAs): and, (2) to examine whether a relationship existed between the various profiles and participants' use of self-regulated learning strategies and proportional learning gains.

We addressed these two goals by conducting two exploratory sets of analyses. The first set examined the number of hints learners received from PAs and whether or not they attempted to follow them. These results proved valuable in elaborating upon the coding framework and interpreting the subsequent results. The second analysis examined the relationship of four different CoRL-HPA profiles and students' SRL strategies, including their selection of sub-goal-related hypermedia pages (i.e., effective use of a content evaluation strategy), and learning.

Method

In this section the participants from analyses 1 and 2 are described separately, though participants from analyses 1 (participants in the PF condition) are a subset of those included in analyses 2 (PF + C conditions). An overview of MetaTutor and its experimental procedure are provided, while a detailed account of the sub-goal setting phase that is the focus of this study is given (including a description of its two PA conditions). The data sources section describes the log files from which all of the data was extracted and the data analyses section describes analysis 2. Analysis 1, which was a mixture of qualitative analyses and descriptive statistics is described in the first two sections of the results.

Participants

Analysis 1. 50 undergraduate students (70% female) from two large public universities in North America participated in this study. Participants were between 18 and 28 years old (*M* = 20.94; *SD* = 2.20) and enrolled in various undergraduate programs, including social sciences (60%) and nursing (2.9%; which was the only discipline related to human biology). Participants' self-reported GPA ranged from 2.4 to 3.9 (*M* = 3.06; *SD* = 0.37). Less than half of the sample (40%) reported taking at least one biology course at the undergraduate level[3]. All participants were paid up to $40 for completion of the two-day, four-hour experiment.

Analysis 2. 107 undergraduate students (72% female) from two large public universities in North America participated in this study. Participants were between 18 and 37 years old (*M* = 20.95; *SD* = 2.88) and enrolled in various undergraduate programs, including social sciences (65%) and nursing (5.3%; which was the only discipline related to human biology). Participants' self-reported GPA ranged from 1.9 to 3.89 (*M* = 3.03; *SD* = 0.47). Less than half of the sample (45%) reported taking at least one biology course at the undergraduate level[4]. All participants were paid up to $40 for completion of the two-day, four-hour experiment.

MetaTutor and Experimental Procedure

MetaTutor is a multi-agent intelligent tutoring system (ITS) and hypermedia-learning environment, which consists of 41 pages of text and static diagrams organized by a table of contents displayed in the left pane of the environment (see Figure 1). The version of MetaTutor used in this experiment is composed of material on the human circulatory system, which it is designed to teach participants about during their interaction with the four PAs embedded in the system. There are two experimental conditions that learners are randomly assigned to with MetaTutor (described below).

On day one of the MetaTutor experiment, participants completed a demographics questionnaire, and pretest on the human circulatory system as well as on their understanding of SRL. Day one generally took 20 to 30 min for participants to complete. On day two, participants interacted with MetaTutor for two hours, after which they immediately completed a posttest on the human circulatory system.

Prior to the beginning of the learning session, participants were instructed in a think-aloud protocol, the Tobii T60 eye-tracker was calibrated to each participant

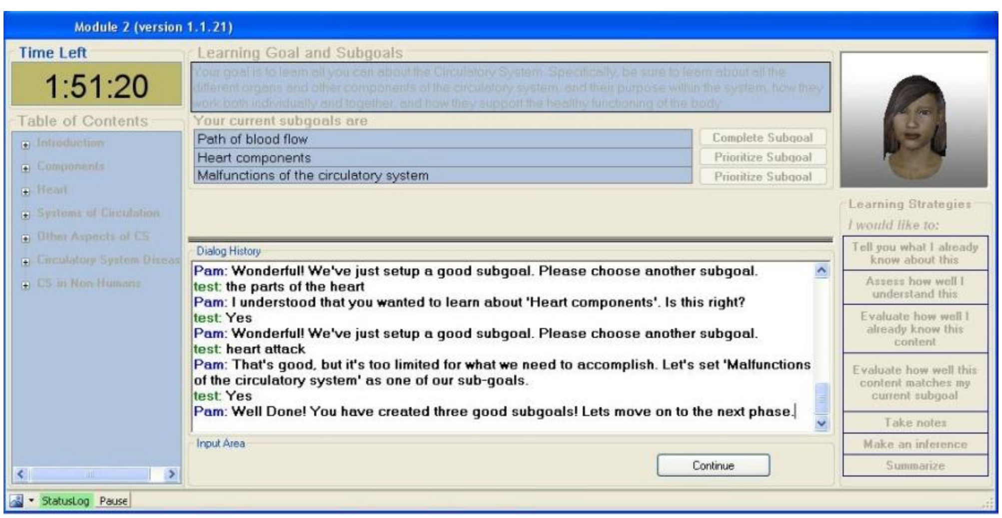
[3] With the exception of gender, demographic information is based on data collected from 35 participants (70% of sample), as the remaining participants did not provide this information.

[4] Demographic information is based on data collected from 76 participants (71% of sample), as the remaining participants did not provide this information.

individually, and audio and video capture equipment were tested and activated. Several tutorial videos featuring instructions from either a human agent or a combination of a human and PA were shown to the participant at the beginning of the session to explain how to navigate the system.

The *goal setting phase* of this study could take up to approximately 15 min and included, in addition to the SG setting task itself, the self-introduction of the PA, prior knowledge activation PKA, where the PA requested participants to tell it everything they knew about the circulatory system, and a brief introductory video instructing participants on how to set an appropriate SG and the PA's role in this process. The SG setting task is the focus of our study and ranged between one minute and 12 seconds and three minutes and 45 seconds. This difference in time is due to participants' varying abilities to set SGs for learning as much as they could about the circulatory system at an appropriate level of detail, as well as the scaffolding strategy deployed by the PA. Ideal SGs outline, at a level of detail that is not too broad or too specific, something the participant wishes to learn about and understand regarding the circulatory system (the main goal, which the SGs are organized around).

In this study, participants were prompted to set three SGs while being mindful of their overall learning goal: *to learn all they can about the circulatory system, specifically, to learn about all the different organs and different components of the circulatory system and their purpose within the system, how they work both individually and together, and how they support the healthy functioning of the body*. The feedback the PA provided to learners following each attempt to propose a SG varied depending on the experimental condition. In the prompt and feedback condition (PF), the PA provided information related to the relevancy and proximity of learners' proposed SG to one or more of the seven ideal SGs[5]. An alternative SG was only proposed after three successive and unsuccessful attempts or if the SG was too specific (see Figure 2). In the control (C) condition the PA immediately proposed an alternative SG if the proposed one was not appropriate.



[5] (a) path of blood flow, (b) heartbeat, (c) heart components, (d) blood vessels, (e) blood components, (f) purpose(s) of the circulatory system, and (g) malfunctions of the circulatory system.

Figure 1. Screenshot of MetaTutor Interface and Goal Setting Learner-PA Interaction Example for the Feedback Scaffolding Condition.

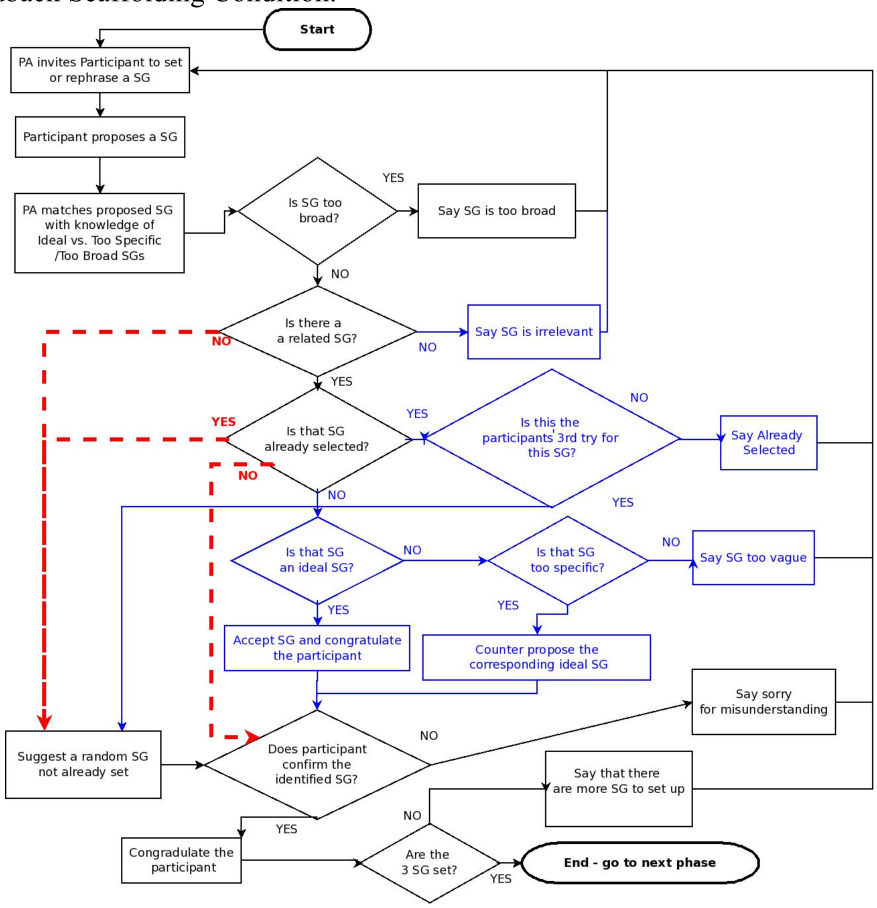
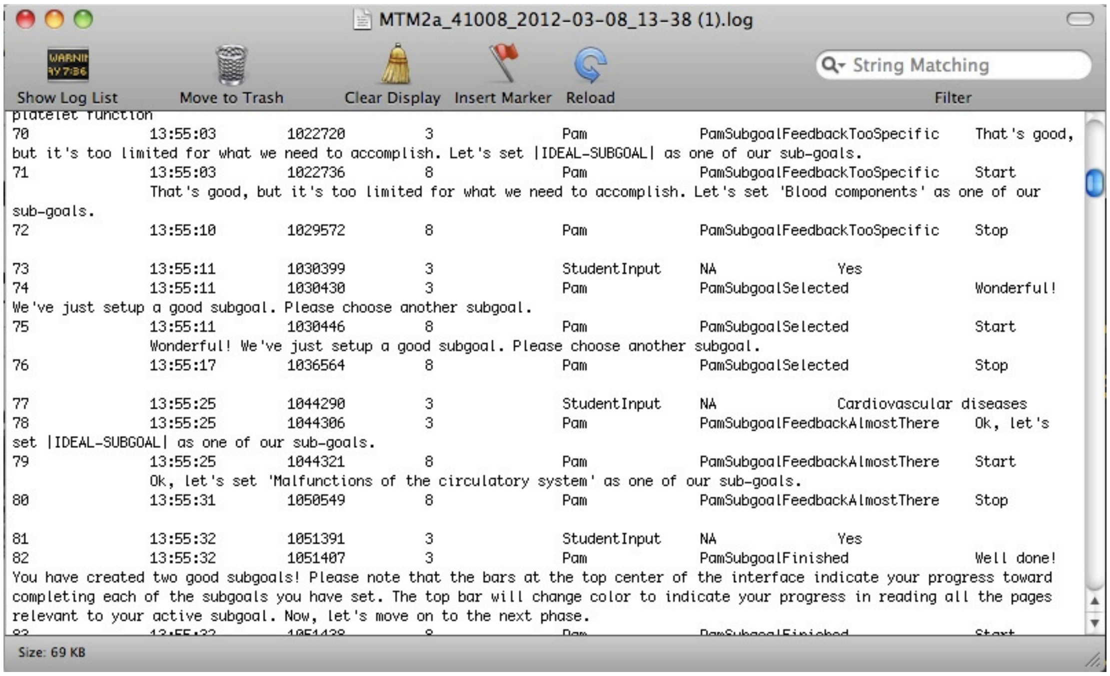


Figure 2. PA Decision Tree. The blue boxes and directional arrows in this figure are decision nodes and paths available to the PA only in the Feedback condition, while red thick paths are those that it takes in the Control condition. SG indicates sub-goal.

Data Sources

MetaTutor log files recorded all interactions between the user and the system. Figure 3 displays an excerpt of such a log during the SG setting phase where column 1 represents the count of the recorded events, columns 2 and 3 are the absolute and relative time (in ms) since the beginning of the session, and column 4 identifies the type of the event dummy coded by a number. In the case of interactions between the agent and the participant (events of type 3), column 5 represents the initiator of the action (either the PA or the student), column 6 corresponds to the identifier of the script used (by the agent) and column 7 is the associated text either typed as an input by the student or displayed and spoken as an output by the agent.


MTM2a_41008_2012-03-08_13-38 (1).log
Show Log List Move to Trash Clear Display Insert Marker Reload String Matching Filter
```
platelet function
70      13:55:03    1022720    3    Pam    PamSubgoalFeedbackTooSpecific    That's good,
but it's too limited for what we need to accomplish. Let's set |IDEAL-SUBGOAL| as one of our sub-goals.
71      13:55:03    1022736    8    Pam    PamSubgoalFeedbackTooSpecific    Start
        That's good, but it's too limited for what we need to accomplish. Let's set 'Blood components' as one of our
sub-goals.
72      13:55:10    1029572    8    Pam    PamSubgoalFeedbackTooSpecific    Stop

73      13:55:11    1030399    3    StudentInput    NA    Yes
74      13:55:11    1030430    3    Pam    PamSubgoalSelected    Wonderful!
We've just setup a good subgoal. Please choose another subgoal.
75      13:55:11    1030446    8    Pam    PamSubgoalSelected    Start
        Wonderful! We've just setup a good subgoal. Please choose another subgoal.
76      13:55:17    1036564    8    Pam    PamSubgoalSelected    Stop

77      13:55:25    1044290    3    StudentInput    NA    Cardiovascular diseases
78      13:55:25    1044306    3    Pam    PamSubgoalFeedbackAlmostThere    Ok, let's
set |IDEAL-SUBGOAL| as one of our sub-goals.
79      13:55:25    1044321    8    Pam    PamSubgoalFeedbackAlmostThere    Start
        Ok, let's set 'Malfunctions of the circulatory system' as one of our sub-goals.
80      13:55:31    1050549    8    Pam    PamSubgoalFeedbackAlmostThere    Stop

81      13:55:32    1051391    3    StudentInput    NA    Yes
82      13:55:32    1051407    3    Pam    PamSubgoalFinished    Well done!
You have created two good subgoals! Please note that the bars at the top center of the interface indicate your progress toward
completing each of the subgoals you have set. The top bar will change color to indicate your progress in reading all the pages
relevant to your active subgoal. Now, let's move on to the next phase.
```
Size: 69 KB

Figure 3. Sample excerpt from a MetaTutor log file during the sub-goal setting phase.

Data Analyses

The CoRL-HPA framework. The final coding scheme contained four profiles, which two trained coders used to code the PA's responses to learners' proposed SGs from 247 segments (κ = 0.98). One coder coded an additional 240 segments. Therefore, we had a total of 487 segments coded from 107 participants (i.e., 50 participants from the Feedback [FB] condition and 57 from the Control [C] condition). The learner-PA interactions were segmented based on dialogue turns between the PA and the learner where the PA provided feedback regarding the learner's proposed SG.

In our inferential analyses, which examined the relationship of the four different CoRL-HPA profiles and students' SRL strategy use, selection of SG-related pages, and learning, we did not include the interaction that resulted in the setting of the third SG because only a few (69.2 %) participants completed their third SG during the learning session. Its inclusion would have, therefore, limited our analyses of the relationship between CoRL profiles and subsequent learning and SRL strategy use. Furthermore, in cases where the PA and the learner spent more than one dialogue-turn (e.g., segment) setting up an appropriate SG (i.e., co-regulation profiles) we used the first segment as the profile code for that particular SG. The unit of analyses was the PA-learner interaction for each individual SG because learners could have different interactions between the first two SGs we examined for each of them.

Examining the relationship between CoRL-HPA profiles and learners' subsequent SRL strategies. In order to determine the relationship between the participants' CoRL-HPA profiles and the SRL processes they engaged in during the learning session (on pages which were related to a SG that they set at the beginning of the session), we performed a one-way ANOVA. CoRL-HPA profile was used as the independent variable and the mean number of SRL processes was used as the dependent variable. There were no outliers in the data set, however, the variables yielded moderately skewed data, and so we performed a square root transformation prior to running the analysis. Levene's test of equality of variances was violated for mean number of SRL processes, $F(3, 210) = 5.77$, ($p < .01$), therefore a more stringent alpha level ($p < .01$) was used in order to identify significant differences (Tabachnick & Fidell, 2007).

Examining the relationship between CoRL-HPA profiles and learners' selection of SG-relevant pages. We also examined how the participants' CoRL-HPA profiles related to the proportion of pages they selected and viewed (for more than 15 seconds[6]) that were relevant to the SGs they set during the initial SG setting phase. We did this by performing a one-way ANOVA, with profile as the independent variable and proportion of SG-relevant pages as the dependent variable. Our data did not contain any outliers, however, our data was moderately skewed, so we performed a square root transformation prior to running the analysis.

Examining the relationship between CoRL-HPA profiles and learners' proportional learning gains. In order to assess differences in participants' pretest to post-test learning we calculated their proportional learning gain (D'Mello et al., 2010), scores using the below formula.

$$\frac{posttest\ score - pretest\ score}{1 - pretest\ score}$$

We made a revision to the original formula because negative values suggest that participants unlearned material, which is unlikely, especially in MetaTutor where it is more probable that they simply made a few lucky guesses on pretest items. The revision involved us replacing negative values with a zero. Therefore, in cases where the pretest score was greater than the posttest score, learners' proportional learning gain was zero.

In order to examine participants' CoRL-HPA profiles with their proportional learning gains relative to the SGs they set during the SG setting phase, we performed a one-way ANOVA with profile as the independent variable and proportional learning gain as the dependent variable. We did not encounter any outliers in the data set, however, the data was severely negatively skewed so we performed a logarithmic transformation.

Results

The below results are organized to present the multi-stage development of the CoRL-HPA framework and the accompanying analyses.

Developing the Co-Regulated Learning Human-PA Framework: Part 1

The CoRL-HPA framework was developed by first experimenting with Graesser and colleagues' (1995) five-step dialogue framework to code the learner-PA interactions during the SG setting phase of MetaTutor. We adapted the framework through iterative, qualitative analysis to capture the different PA scaffolding and learner behavior themes that emerged. Our analyses led us to develop a framework that involved four steps (Harley, Taub, Bouchet, & Azevedo, 2012):

[6] 15 seconds was used as the threshold based on average reading times to ensure that participants had decided to read the page and not just skim through and move on.

1. PA invites student to set up a sub-goal (SG)
2. Student proposes a sub-goal (SG)
3. PA gives feedback on proposed sub-goal (SG)
4. Student responds to feedback.

From these four steps, two different high-level profiles emerged that describe learners' navigation through them: a *fast-track* (see Figure 4) and an *intervention* (see Figure 5) profile. The two profiles are distinguished by the affordance or non-affordance of students being provided with the opportunity to try to counter-propose a SG based on feedback from the PA. Feedback was characterized as either a hint (content feedback) or provision of an example (procedural feedback). A hint provided students with information that their proposed SG was either too specific, too general, related to a previously set SG (if any), or unrelated to the human circulatory system. In the case where learners were provided with an example, the PA, after several unsuccessful attempts on the part of the learner, played an instructional video that walked students through an example of a student setting an appropriate SG about the human circulatory system. We classified the setting of a SG where feedback and the opportunity to try again were provided as an *intervention profile*. Alternatively, the CoRL-PA trajectory of setting a SG could be classified as a *fast-track* profile if the PA provided the learner with an answer (even if feedback was provided as to why the original answer was not appropriate) or if the PA simply confirmed their understanding of the learners' proposed SG. These two profiles have the potential to provide learners with fundamentally different experiences while setting SGs, which can range from a very quick experience with little collaboration (either because the student is able to independently set a proper SG or because the PA spoon feeds the learner) or one in which one or more dialogue turns can take place between the PA and learner and better represents a collaborative effort to establish a SG.

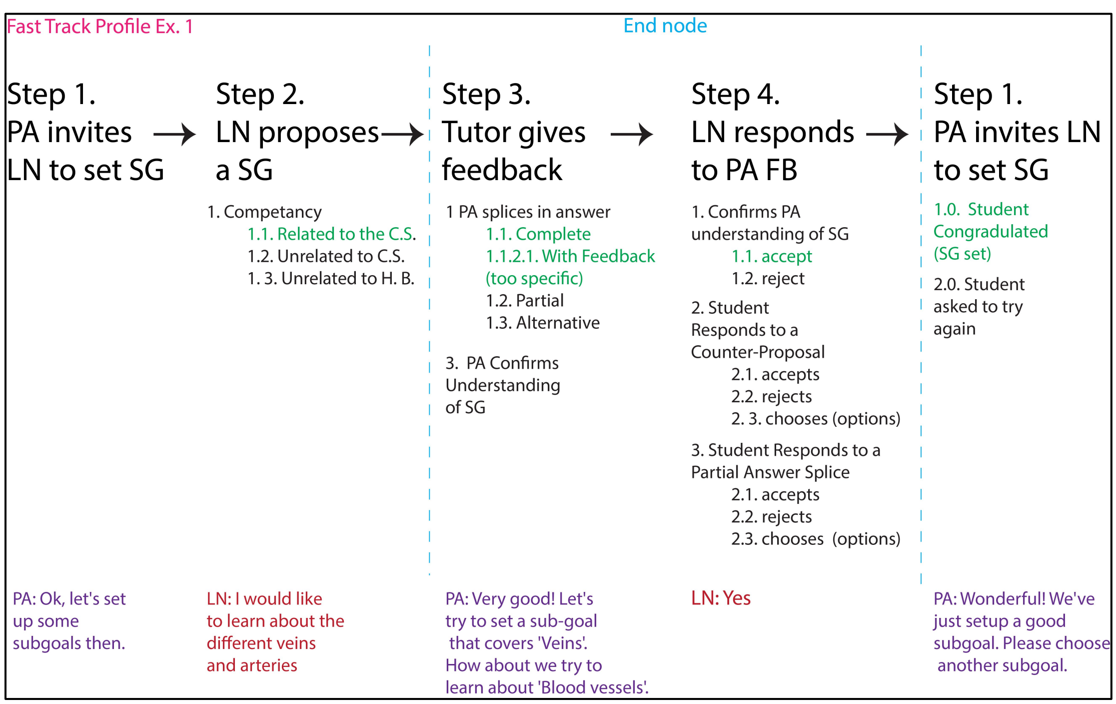


Figure 4. Fast-track profile. PA = pedagogical agent and LN = learner.

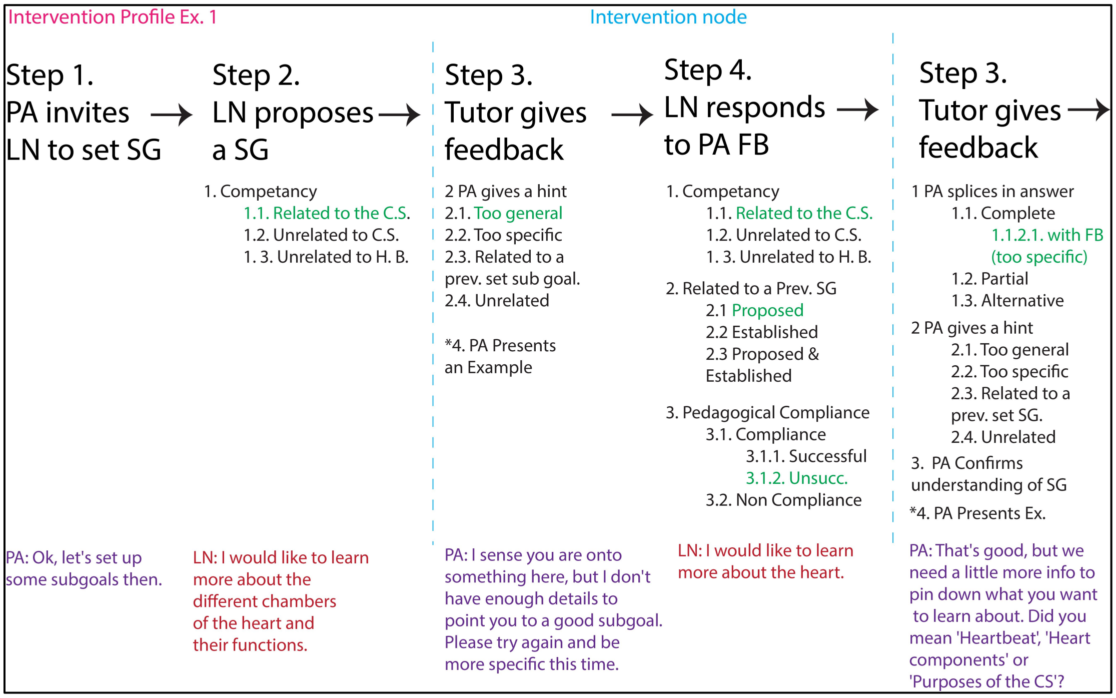


Figure 5. Intervention profile.

Analyses 1: Good Advice: Taken or Left?

Based on these two profiles, two trained coders coded 50 participants' SG phase log files and identified hints (from the other types of feedback and dialogue interactions) from 274 segments (κ = 1.00). All 50 participants were assigned to the FB condition because no hints are given in the C condition. Figure 6 reveals that most participants received between one and three hints across their SG setting phase.

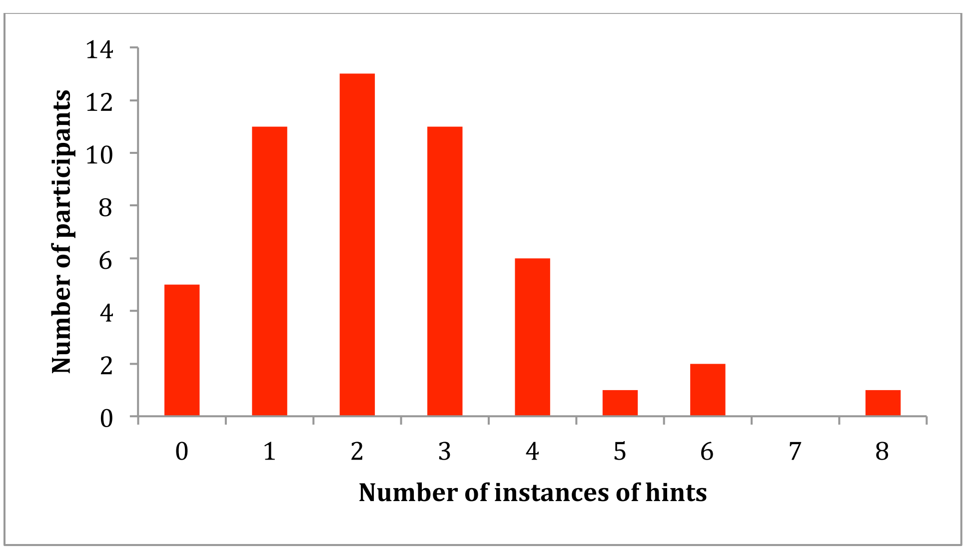


Figure 6. Histogram of frequency of hints by number of participants.

In addition to identifying the type of CoRL-HPA, we were also interested in whether learners used the hints that the PA provided to them, which we called learners' pedagogical compliance (PC). Learners' PC was specific to the hint prompt from the PA and was coded as: *pedagogical compliance-yes* (PC-Y), *non-compliance-no shift* (NPC-NS), or *non-compliance-abandonment* (NPC-A). The PC-Y code was assigned when the learner counter-proposed a SG in response to the PA's hint that was either more specific or more general than the initial proposed SG (regardless of which direction the PAs hint was in) or a shift toward a new topic if the proposed SG was deemed irrelevant or related to a previously established SG. The direction that learners counter-proposed their SG was not coded because the majority of students (97.1%) were not biology majors and many, additionally, had low pretest scores. Therefore, we could not be sure that learners knew the hierarchical relationships, in terms of specificity, between the different circulatory system components they proposed, prompting us to focus on whether they recognized that a change in specificity was needed (from the PAs hint).

The superordinate code NPC was assigned when the learner did not make an attempt to adjust their SG toward the PA's recommendation. There were two subordinate codes for this category. The first, NPC-NS, was assigned when a hint for the learner to be more general or specific was followed up by the learner attempting to make only surface changes to their proposed SG (e.g., using a synonym, pluralizing, etc.). In the case of a hint to change topics (due to relatedness to a previous SG or the proposed SG being unrelated to the human circulatory system) the learner would remain focused on the topic. If the learner switched to a new, but still irrelevant topic it would be coded as PC-Y (because we cannot know if they knew it was related). The second NPC code, NPC-A was used if learners abandoned the SG they had proposed and received feedback on and instead counter-proposed a different topic regarding the circulatory system when the hint the PA prescribed was to be more general or specific.

Based on these codes, the 50 participants were coded by the same coders, where one coder coded all 50 participants' logs and the second coded 31 logs and 71/110 segments ($\kappa = 0.76$). Our coding revealed that learners attempted to follow the advice that the PA provided more often than ignoring it or abandoning their SG (see Figure 7).

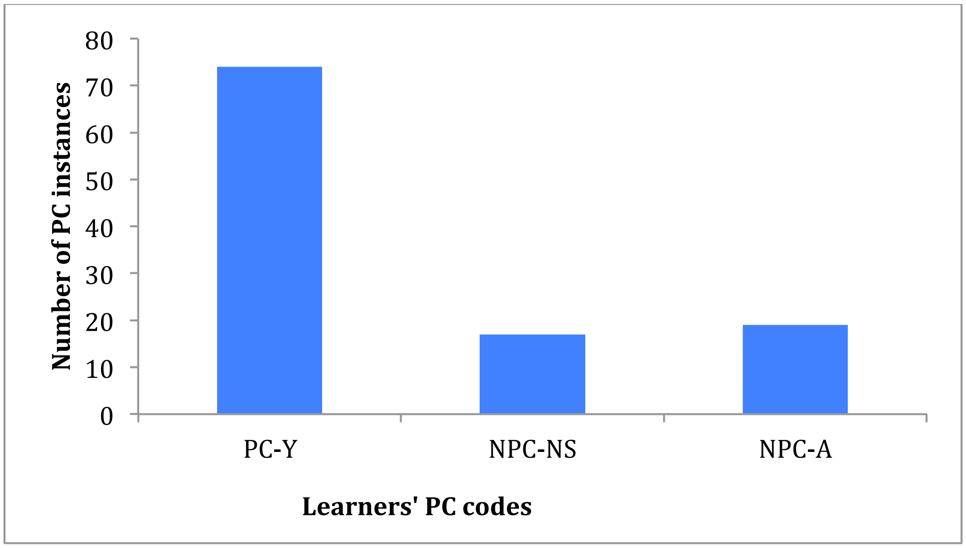


Figure 7. Histogram of number of PC instances by type of PC.

Developing the Co-Regulated Learning Human-PA Framework: Part 2

In order to explore the PA-learner interactions during the SG phase we increased our focus on the nature of the feedback that the PA provided to students in response to proposed SGs. Specifically, we were interested in classifying the PAs feedback based on the degree of scaffolding it provided students with. This interest emerged from pedagogical literature examining the competing goals of students' desires (and expectations) to be given the 'right answer' vs. research illustrating the benefits of students active involvement in and engagement with learning material (Kember & Mckay, 1997; Heikkila & Lonka, 2006). With this orientation in mind and the previous results regarding learners' compliance with the PAs' hints we revisited the CoRL-HPA framework. From reviewing all of the PAs' responses to students proposed SGs we came up with four categories that captured the degree of scaffolding or direction that the PA provided the students with.

Spoon-feeding Type 1 (SPF1). SPF1 was assigned when the PA told learners what the SG they should set. In this case no hints were provided. We nicknamed SPF1 as 'baby food' because the learner wasn't involved in setting the SG nor were they given any information regarding why their proposed SG was inappropriate. An example of an interaction that would be coded as SPF1 would be the learner proposing an inappropriate SG, such as "brain" and the PA responding "Ok, how about we try to learn about 'Heartbeat'?".

Spoon-feeding Type 2 (SPF2). SPF2 was assigned when the learner was given the answer, but the answer was accompanied with feedback regarding why it was/wasn't appropriate. SPF2 included instances where the PA provided learners' with choices regarding which SG they would like to set when the proposed SG was related to the options it proposed. We nicknamed SPF2 because of the (incremental) improvement in the learners' involvement and awareness of the SG setting task, similar to being led somewhere. An example of an interaction that would be coded as SPF2 would be the learner proposing an inappropriate SG, such as "blood transport" and the PA responding “that's good, but we need a little more info to pin down what you want to learn about. Did you mean 'Blood components', 'Purposes of the circulatory system' or 'Malfunctions of the circulatory system'?”

Co-Regulation (CR): CR was assigned when the PA provided the learner with a hint (not a counter-proposed SG) regarding why their SG was inappropriate and a request for them to try again rather than providing the answer. We classified this code as co-regulation because it is an example of the PA and learner working together, collaboratively, toward a shared objective (to set up three appropriate SGs). This type of response from the PA affords the student a greater degree of involvement in setting their own learning objective for the learning session as well as an opportunity for them to learn from their previous attempts and improve. An example of an interaction that would be coded as CR would be the learner proposing an inappropriate SG, such as “heart” and the PA responding “I sense you are onto something here, but I don't have enough details to point you to a good sub goal. Please try again and be more specific this time.”

Right Answer (RA). RA was assigned when the PA clarified its understanding of the learners’ proposed SG. This involved the PA re-stating what the learner had said in the same words that the appropriate SG were programmed as to make sure that no errors in natural language processing (NLP) had occurred. We classified this type of response as RA because the PA recognized one (or more) appropriate SG in the learners’ proposal and therefore sought to clarify rather than re-direct their goal setting. An example of an interaction that would be coded as RA would be the learner proposing an appropriate SG, such as “I would like to learn about the diseases that could affect the circulatory system” and the PA replying “I understood that you wanted to learn about 'Malfunctions of the circulatory system'. Is this right?”

Analyses 2: The Relationship Between CoRL-HPA Profiles and Participants’ Learning, SRL Strategy Use, and Selection of SG-Relevant Pages

Examining the relationship between CoRL-HPA profiles and learners’ subsequent SRL strategy use. Our results from the ANOVA indicated a statistically significant main effect of CoRL-HPA; $F(3, 210) = 38.87$, $p < .01$, partial $\eta^2 = .36$. Based on the pairwise comparison results using a Bonferroni correction, all of the profiles differed significantly regarding the mean number of SRL processes used except between RA and SPF2 profiles. More specifically, those with the CR profiles used a significantly higher mean number of SRL processes ($M = 1.79$, $SD = 0.40$) than those with the RA profile ($M = 1.28$, $SD = 0.55$), the SPF1 profile ($M = 0.85$, $SD = 0.35$), and the SPF2 profile ($M = 1.33$, $SD = 0.47$). Participants with an SPF1 profile used a significantly lower mean number of SRL processes than all of the other participants with other CoRL-HPA profiles in the study. See Table 1 for the descriptive statistics.

Table 1

Descriptive Statistics with Mean Number of SRL Processes as the Dependent Variable

Profile	*N*	*M*	*SD*
1 – CR	49	1.79	.40
2 – RA	71	1.28	.55
3 – SPF1	61	0.85	.35
4 – SPF2	33	1.33	.47
Total	214	1.28	.56

Examining the Relationship Between CoRL-HPA Profiles and Learners' Selection of SG-Relevant Pages. A one-way ANOVA revealed a statistically significant main effect of CoRL-HPA on the proportion of SG-relevant to irrelevant pages that learners visited, $F(3, 210)$, $p = .000$, partial $\eta^2 = .16$. A post-hoc, Bonferroni analysis indicated that participants with the CR profile had significantly higher proportions of SG-relevant to irrelevant page visits ($M = 0.47$, $SD = 0.26$) than those with the RA profile ($M = 0.33$, $SD = 0.28$) or the SPF1 profile ($M = 0.17$, $SD = 0.22$), however, there was no statistically significant differences between the proportions for participants with the CR profile and the SPF2 profile ($M = 0.39$, $SD = 0.26$). Moreover, participants with the RA profile did not significantly differ from those with the SPF1 profile in terms of the proportion of SG-relevant pages selected. See Table 2 for the descriptive statistics.

Table 2

Descriptive Statistics with Proportion of Relevant Pages as the Dependent Variable

Profile	*N*	*M*	*SD*
1 – CR	49	.47	.26
2 – RA	71	.33	.28
3 – SPF1	61	.17	.22
4 – SPF2	33	.39	.26
Total	214	.33	.28

Examining the Relationship Between CoRL-HPA Profiles and Learners' Proportional Learning Gains. The one-way ANOVA failed to reveal a significant main effect of CoRL-HPA on learners' proportional learning gains, $F(3, 210) = 1.43$, $p = .23$.

Table 3

Descriptive Statistics with Learning Gains as the Dependent Variable

Profile	*N*	*M*	*SD*
1 – CR	49	40.10	37.27
2 – RA	71	38.57	35.41
3 – SPF1	61	32.31	30.34
4 – SPF2	33	35.54	35.24
Total	214	36.67	34.36

Scientific Contributions of the Study

Our qualitative analyses of learners' dialogue-turns with a PA during the goal setting phase of MetaTutor has led us to develop a comprehensive human-PA co-regulated learning framework for classifying and examining the different interactional patterns that take place between learners and the PA while they try to set up SGs. Through the iterative development of the framework we have identified several interesting features of the interactions between the PA and learners during the SG setting phase of MetaTutor. First, our early work with the framework underlined the importance of a specific type of feedback from the PA, hints, in providing an important opportunity for learners to have more involvement and therefore a better chance to improve their ability to set appropriate SGs. Our results revealed that in most cases learners were responsive to PA's hints, suggesting that the PA is effective in deploying them. This finding is interesting from the point of view that the PA is occupying the place of an expert HT and learners are responding to him or her accordingly. This 'buy in' is an important criteria for co-regulated learning to occur between learners and PAs because no scaffolding can take place if learners simply ignore what the PA has to say and / or attempts to game (cheat) the system.

In order to better understand the implications of learners' mostly compliant interactions with the PA, we expanded our coding framework to examine the nature of the feedback that the PA provided to students in response to proposed SGs. Our results conformed with our hypothesis where students who established their SGs with the PA in a co-regulatory manner engaged in the most SRL strategies, had the highest ratio of SG-relevant to non-relevant page visits, and had the highest proportional learning gains. Relatedly, the opposite was true for students with SPF1 interactions. These results provide further evidence that engaging students with learning material, including providing them with immediate, directional feedback and the opportunity to try again, can lead to better learning outcomes and more strategic learning behaviors.

It is likely that students with CR interactions engaged in more SRL strategies and selected more relevant pages because they felt more committed to the SGs they had jointly set with the PA than those who had been assigned the SGs (SPF1 and SPF2). For those students who were able to propose an appropriate SG (RA profile), it is likely that they may have felt more confident, perhaps overconfident, in their ability to complete the SG and therefore invested less effort in SRL strategies and more time exploring unrelated content out of curiosity. Although none of the profiles significantly differed in terms of proportional learning gains, CR learners marginally outperformed RA learners, which could be the result of the previously proposed difference between these two profiles.

In line with these interpretations are the differences between SPF1 and SPF2 learners, in which learners who received feedback regarding why their proposed SG was not appropriate used more SRL strategies, selected more relevant pages, and outperformed students who did not.

One of the limitations with this research was that learners could be assigned to two different profiles, one for each of their SGs. Future analyses will examine the relationship between similar and different combinations of profiles and learners' SRL strategy use, selection of relevant pages, and proportional learning gains. Future work will also examine the relationship between learners' interactions with the PA during the SG setting phase and the learning session.

The major outcome of these analyses has been to empirically demonstrate that co-regulated learning interactions can take place between learners and PAs and that they can lead to increased SRL strategy use, selection of more relevant pages, and higher proportional learning gains than more traditional closed-ended externally-regulated interactions (e.g., the PA providing a prompt with an instruction or the right answer, but no back and forth collaborative dialogue or problem solving). Future work will examine instances and outcomes of other-regulated learning interactions between PAs and learners in ITSs, including MetaTutor.

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