

# Investigating the Effects of Cognitive and Metacognitive Scaffolding on Learners using a Learning by Teaching Environment

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**Abstract:** We compared the effects of cognitive and metacognitive scaffolding on students' performance within a learning-by-teaching intelligent tutor for algebra. Results revealed that metacognitive scaffolding facilitated learning for low prior ability learners while high prior ability students' performance was obstructed by their refusal to follow the hints. Moreover, the study found that metacognitive actions related to self-regulatory learning's reflection subfunction correlates negatively to the learning outcomes of low ability students.

**Keywords:** Intelligent tutoring systems, learning-by-teaching, scaffolding, self-regulated learning, SimStudent

## 1. Introduction

*Scaffolding* refers to the contingent and faded support aimed at improving students' performance, which closely relates to the Zone of Proximal Development (ZPD) theory (Vygotsky, 1978). Scaffolding motivates students to learn complex ideas that are beyond their grasp (Jumaat and Tasir, 2015). Research has shown evidence that one's learning can be improved through scaffolding in technology-enriched learning environments. Scaffolding triggers students to express knowledge and skills in various ways (e.g. feedback, transformation, self-explanation, and diagramming), that they will otherwise miss without prompts coming from a more enabled peer, which may result in missed opportunities to promote recall of prior knowledge, deeper understanding, and processing for knowledge integration (Demetriadis et al., 2008). Scaffolds can help learners improve their learning both at cognitive and metacognitive levels (Azevedo and Hadwin, 2005).

Cognitive scaffolding supports learning process by directing students towards learning-appropriate goals such as focusing their attention on the task at hand (Demetriadis et al., 2008) and assisting them to overcome barriers in solving problems through modelling, providing hints, and coaching techniques (Ahern, 2009). Metacognitive scaffolding supports learning by focusing students' awareness on their own cognition and on their understanding of the activities they are engaged in (Jumaat & Tasir, 2015). Through this approach, students could be motivated to plan strategies, evaluate and monitor learning process and performance (Efklides, 2008) based on their set goals, and adjust strategies to improve task effectiveness and their performance (Kinnebrew et al., 2014). Such executive functions are important components of self-regulated learning (SRL).

While older ITSs provide cognitive, domain-level support in forms of on-demand help and feedback (Roll, et al., 2006; Luckin and Du Boulay, 1999; Conati and VanLehn, 2000), the number of ITSs providing support for the activation of metacognitive skills have grown. Some examples of these ITSs are Geometry Cognitive Tutor (Schwonke et al., 2013), SimStudent (Matsuda et al., 2014), Betty's Brain (Leelawong and Biswas, 2008) and SlideTutor (Feyzi-Behnagh et al., 2014). Despite extensive research in this field, the question on how these types of support affect students is still under investigation. We hope to contribute to the body of work on the relationship between

scaffolding and learner achievement. We investigate whether different types of support benefit different types of students in different ways and how learner usage patterns mediate these effects. In this paper, we investigate the effect of both cognitive and metacognitive supports on students using SimStudent, a learning-by-teaching ITS for algebra. Our research questions are:

1. What is the effect of cognitive and metacognitive scaffolding on learners' achievement?
2. How do cognitive and metacognitive scaffolding affect the achievement of learners with varying levels of prior knowledge?
3. Do hint and resource usage mediate learners' achievement?

## 2. Research Hypotheses

Scaffolding was shown to improve student performance in problem solving (Roll et al., 2006; Matsuda et al., 2014; Leelawong and Biswas, 2008). We hypothesize that students in both cognitive and metacognitive conditions will have increased achievement given these types of scaffolding.

Cuevas et al. (2002) found that cognitive and metacognitive scaffolding effects were strongest for low ability participants. Luckin and Hammerton (2002) and Weerasinghe and Mitrovic (2006) have shown that metacognitive scaffolding benefits low prior knowledge learners more than high prior knowledge learners. Thus, we hypothesize that lower prior ability students will benefit from scaffolding, with greater learning gains, among learner classes.

Previous work demonstrates that cognitive learning strategies (Berthold et al., 2007) and metacognitive prompts (Sonnenberg and Bannert, 2015; Jumaat and Tasir, 2015) mediated students' learning outcomes. We hypothesize that students who make greater usage of cognitive and metacognitive scaffolds and resources benefit more than those who have lesser utilization of these affordances.

This paper contributes to the literature in that it provides us with evidence about how these different types of support might affect different students. Moreover, most research conducted in this area use data from western, English-speaking participants. Our study used a data set collected through ITS deployment in the Philippines, providing cross-cultural data that is not always available.

## 3. The Learning Environment

### 3.1 SimStudent

SimStudent is a virtual teachable agent that learns procedural skills inductively from the examples given by a human tutor. SimStudent attempts to solve the problem one step at a time, occasionally asking the human tutor about the correctness of each step or requesting for a demonstration. From the feedback and demonstrations, SimStudent generates production rules that represent the skills learned (Matsuda et al., 2014).

### 3.2 APLUS: Artificial Learning Environment using SimStudent

In order to use SimStudent as a teachable agent for peer tutoring, it is embedded into a game-like learning environment called APLUS (Artificial Peer Learning environment Using SimStudent). Figure 1 shows an annotated sample screenshot of APLUS. In this example, the student tutor teaches a customizable pedagogical agent, visualized with an avatar named Alex ("c" in Figure 1). In the *tutoring interface* ("b" in Figure 1), the tutor and Alex, the SimStudent, collaboratively solve problems. The tutor gives the problem  $3x+6=15$  for Alex to solve. Alex suggests a transformation and enters "add 3". After performing a step, Alex verifies with the tutor if the step is correct. The tutor responds by clicking the feedback buttons (Yes/No) ("d" in Figure 1). If the tutor gets stuck or is preparing for tutoring, he/she can access the examples and other system resources by clicking the corresponding tab in the resources bar ("a" in Figure 1). The student tutor can measure how much Alex has learned by quizzing. Quizzes can be administered multiple times. Mr. Williams ("f" in Figure 1), the metatutor agent, presents the summary of the SimStudent's performance on the quiz

(“e” in Figure 1). SimStudent cannot proceed to the next level quiz unless all equations in the current level are correctly solved. The student tutor can also ask Mr. Williams for help when they encounter difficulties.

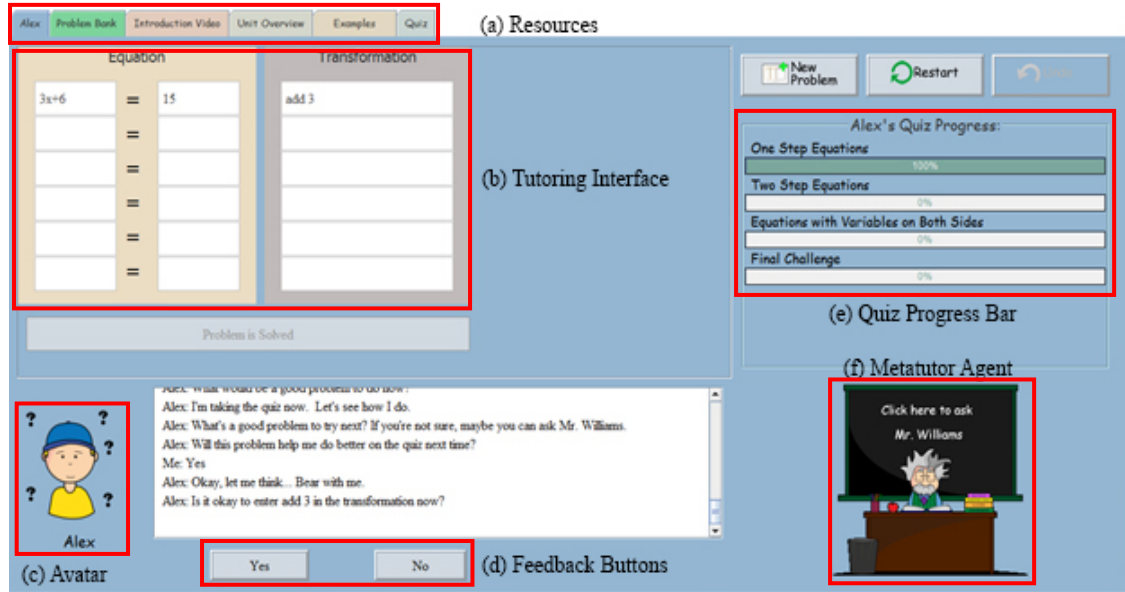


Figure 1. The SimStudent Interface.

In this study, we used modified versions of this ITS to provide adaptive scaffolding in two ways: (1) *Cognitive scaffolding* provides adaptive assistance on how to solve equations. When the tutor asks Mr. Williams about the correctness tutee’s action (e.g. “*Is this step correct?*”), *feedback* is given (i.e. “*No, subtract 10 would not be the right thing to do.*”). When the tutor does not know the correct next step and asks for help (i.e. “*What’s the next step?*”), Mr. Williams answers by *demonstrating the step* (e.g. “*What do you get when you apply the transformation ‘subtract 5/9’ to  $j+5/9$ ? You need to enter  $j$  on the left side.*”). (2) *Metacognitive scaffolding* provides adaptive assistance on how to teach or proceed with tutoring. When the tutor requests assistance (e.g. “*What should I do now?*”), Mr. Williams provides one of the four types of metacognitive help: (a) *quiz assistance* to suggest when students should take the quiz and why, (b) *problem selection assistance* to suggest what problem students should pose next and why, (c) *resource assistance* to suggest when students should review a particular resource and why, and (d) *impasse recovery assistance* to suggest a problem restart or give a new problem when students are stuck for a predetermined amount of time.

Aside from the adaptive scaffolding the system provides, APLUS is embedded with features supporting tutors in activating self-regulatory processes. These affordances aid tutors in setting their goals by learning what the task is all about, planning strategies by understanding the subject domain, teaching their tutee, and assessing their own understanding and performance. These features are described elsewhere (Matsuda et al., 2014, Matsuda et al., 2016).

## 4. Methodology

### 4.1 Structure of the Study

The study took place over five consecutive days and one day two weeks after the fifth day. On day 1, the students completed a 40-minute pre-test to assess their proficiency in solving equations and a pre-session survey to assess motivational attitudes towards learning algebra. On day 2, students were given instructions on how to use the software, after which they started tutoring their SimStudent. Tutoring sessions took place for three consecutive days. Each session lasted 40 minutes. Following the tutoring sessions, students were given a 40-minute post-test (Procedural Skill Test and Motivational Test) on day 5. A delayed post-test for Procedural Skill Test was administered two weeks after the fifth day.

## 4.2 Written Tests

The Procedural Skill Test contained 10 problems; 1 one-step equation, 3 two-step equations and 6 equations with variables on both sides. Three versions of isomorphic tests were randomly used for pre-, post-, and delayed-tests to counterbalance the test differences.

The Motivational test (MT) was used to assess students' motivation in learning Algebra before and after the intervention. The pre-session MT consisted of 15 questions: 14 7-point Likert-style questions with response scale ranging from 1 (*Not all true*) to 7 (*Very true*), and 1 open-ended question to allow participants to explain what he/she thought was easy or hard about learning Algebra. The post-session MT consists of 17 questions, 16 7-point Likert-style questions and 1 open-ended question to explain what the participant thought was easy or hard about teaching SimStudent.

## 4.3 Interaction Logs

The system automatically recorded user-system interactions. The log file records specific parameters such as problems tutored, examples reviewed, hints requested, quiz attempts, and feedback provided (i.e., when the SimStudent asks the tutor for confirmation of an action (Yes/No) and the tutor's explanation of a particular action). It also logs resource usage information, as well as requested (i.e. user-initiated) and proactive (i.e. metatutor-activated) scaffold information.

# 5. Results

The study was conducted in three high schools in the Philippines: two private schools (Davao City and Baguio City) and one public school (Quezon City). A total of 154 Grade 8 students voluntarily participated in the experiment. Each one was randomly assigned to one of the two versions of SimStudent: the experimental condition where metacognitive scaffolding was provided, and the control condition where cognitive scaffolding was provided. Out of those 154 students, 67 took the pre-, post-, and delayed post-tests and participated in all three days of tutoring sessions. Those 67 students were included in the following data analyses.

To investigate the impact of students' prior knowledge on their learning, students were tertile-split (Sabourin et al., 2012) based on their pre-test scores into LPK=low prior knowledge-, APK=average prior knowledge-, and HPK=high prior knowledge- learners. Table 1 shows the number of students per condition, the gender and prior knowledge splits.

Table 1. Number of Students per condition, gender split, and prior knowledge split.

Condition	HPK	APK	LPK
Metacognitive(N=32, M=20, F=12)	8	13	11
Cognitive(N=35, M=23, F=12)	8	13	14

## 5.1 Test Scores

Table 2 shows the average (and standard deviation) of the students' procedural skills test (PST) scores. We used repeated measures ANOVA with condition as between-subject variable and time (pre, post, and delayed) as within-subject variable to examine how the students' test scores varied before and after the interventions and to verify if the effects of scaffolds differ by condition. The results revealed a simple effect of time ( $F(2,130)=10.491, p<0.001$ ). The post-hoc analysis revealed that the students' scores increased significantly from the pre-test to post-test ( $t(66)=-4.223, p<0.001$ ) and pre-test to delayed post-test ( $t(66)=-3.632, p=0.001$ ). However, condition was not a main effect ( $F(1,65)=0.046; p>0.05$ ) indicating no significant difference on the effects of the interventions on students' test scores. Further, there was no statistically reliable interaction between time and condition ( $F(2,130)=0.916, p>0.05$ ).

Table 2: Means (and standard deviations) for Procedural Skills Test (PST).

Condition	Pretest	Posttest	Delayed Posttest
Cognitive (N=35)	4.29(3.77)	5.34(3.59)	5.09(3.98)
Metacognitive (N=32)	4.63(4.16)	5.22(3.96)	5.47(4.17)
Aggregate (N=67)	4.45(3.94)	5.28(3.74)	5.27(4.05)

## 5.2 Effects of Scaffolding on Learning Gains

A between-subject comparison of pre-test scores showed no significant difference in prior knowledge among students in the cognitive and metacognitive groups ( $t(65) = 0.350, p > 0.05$ ), tested using a two-tailed t-test.

We examined whether metacognitive and cognitive scaffolding helped certain students differently by running repeated measures ANOVA for each condition, with time (pre-, post-, delayed post) as within-subject variable and prior knowledge grouping (HPK, APK, LPK) as between-subject variable. Table 3 shows the PST scores and normalized learning gains for each intervention type, grouped by prior knowledge.

Table 3: Procedural Skills Test (PST) scores and normalized gains, by prior knowledge group.

Group		Pretest	Posttest	Delayed Posttest	Normalized Gains
Metacognitive	HPK	9.63(0.52)	9.5(1.07)	9.5(0.76)	-0.0014(0.009)
	APK	5.46(2.73)	6.15(2.97)	6.69(3.40)	0.0073(0.017)
	LPK	0(0)	1.0(1.34)	1.09(1.92)	0.01(0.0134)
Cognitive	HPK	9.5(0.76)	9.5(0.76)	9.63(0.52)	0.1875(0.372)
	APK	5.31(1.60)	6.23(2.95)	6.54(2.79)	0.2833(0.492)
	LPK	0.36(0.50)	2.14(1.70)	1.14(1.61)	0.1825(0.180)

The test revealed a main effect of prior knowledge;  $F(2,29) = 51.178, p < 0.001$  for the metacognitive group. Time was also a main effect:  $F(2,58) = 3.337, p = 0.042$ ; however, no statistically reliable interaction between time and prior knowledge was observed;  $F(4,58) = 1.149, p > 0.05$ . Comparably, learners in the cognitive group also revealed a main effect of time;  $F(2,64) = 5.111, p = 0.009$  and prior knowledge;  $F(2,32) = 82.944, p < 0.001$ , but revealed no statistically significant interaction between time and prior knowledge;  $F(4,64) = 2.037, p > 0.05$ . These results suggest that the effects of both cognitive and metacognitive scaffolding do not vary with learners' prior knowledge.

Table 4: Comparison of normalized gains.

Group		t	p-value
Metacognitive	HPK vs. LPK	$t(17) = -2.194$	$p = 0.042$
	HPK vs. APK	$t(19) = -1.321$	$p > 0.05$
	LPK vs. APK	$t(22) = 0.432$	
Cognitive	HPK vs. LPK	$t(19) = 0.042$	$p > 0.05$
	HPK vs. APK	$t(19) = -0.472$	
	LPK vs. APK	$t(25) = -0.716$	

However, when the learners' normalized learning gains were analyzed to account for the variance in learner' prior knowledge, the results revealed that LPK learners given metacognitive scaffolding posted a higher pre- to post-test learning gains than HPK learners;  $t(17) = -2.194, p = 0.042, d = 0.99$ . A similar analysis revealed no significant difference for the learning gains of HPK and LPK students of the cognitive group;  $t(19) = 0.042, p > 0.05$ . Normalized learning gain was computed using the standard formula:  $normalized\ gain = (posttest - pretest) / (maximum\ possible\ score - pretest)$ . Comparisons of normalized gains between HPK and APK, and LPK and APK

learners, for both groups, revealed no significant differences (see Table 4). Moreover, the analysis revealed that metacognitive group's HPK learners did not gain learning from the intervention.

### 5.3 Hint Utilization

To explore on what might cause LPK learners to gain more from metacognitive scaffolding than HPK learners, we compared the learners' hint utilization. Overall, learners given metacognitive scaffolding exhibited a low hint utilization score, only 14% of the given hints were utilized by the students. Comparison of HPK and LPK learners' metacognitive hint utilization (*FollowedHints*) revealed no reliable difference;  $FollowedHints_{MC\_H\_AVE(SD)} = 0.8(0.7)$  vs  $FollowedHints_{MC\_L\_AVE(SD)} = 1.0(0.6)$ ,  $t(17) = -0.81$ ,  $p > 0.05$ . Moreover, no significant difference was observed in their non-utilization of hints (*IgnoredHints*);  $IgnoredHints_{C\_H\_AVE(SD)} = 3.13(2.23)$  vs  $IgnoredHints_{C\_L\_AVE(SD)} = 4.18(4.02)$ ,  $t(17) = -0.669$ ,  $p > 0.05$ .

Further, we investigated whether utilization and non-utilization of metacognitive scaffolds predict the post-test scores of learners in each ability grouping. We ran centered regression analysis, independently, for HPK and LPK groups. The results revealed that following hints,  $FollowedHints(p > 0.05)$ , had no correlation to HPK learners' posttest (PT) scores while ignoring hints,  $IgnoredHints(p = 0.004)$ , negatively correlates to their posttest scores. The model equation is  $PT = 8.063 - 0.521FollowedHints - 0.429IgnoredHints + 0.668C_{mean}$ ;  $F(3,4) = 14.335$ ,  $p = 0.013$ ,  $r^2 = 0.915$ . The derived model for the group's LPK learners was not significant:  $F(2,8) = 3.314$ ,  $p > 0.05$ .

### 5.4 Resource Utilization

Did the high prior and low prior learners use the resources differently? Does usage mediate learning outcomes? To answer these questions, we performed frequency and regression analyses on both user-initiated and metatutor-prompted resources' usage. Table 5 shows the average (and standard deviations) of HPK and LPK learners' resources' access frequency (RA) and usage duration (DUR).

Table 5. Metacognitive condition's resource utilization, by Prior Knowledge grouping.

Prior Knowledge Group	Resource Access, RA	Duration, DUR (in sec)	Model
HPK	6.25(7.086)	427.96(313.98)	$F(3,4) = 4.485$ , $p > 0.05$
LPK	13.27(11.27)	588.80(523.43)	$F(2,8) = 0.278$ , $p > 0.05$

The comparison between HPK and LPK learners' RA and DUR revealed no significant difference,  $t(17) = -1.547$ ,  $p > 0.05$ , and  $t(17) = -0.771$ ,  $p > 0.05$ , respectively. A regression analysis revealed that both RA and DUR were not predictors of the posttest scores of either HPK or LPK learners, when pretest is controlled.

Table 6. Frequency, means and standard deviations of Metacognitive-coded events.

Metacognitive Events	HPK (N=8)		LPK (N=11)	
	Frequency	Mean(SD)	Frequency	Mean(SD)
SetGoal	2	0.25(0.71)	0	0(0)
Plan	11	1.38(2.77)	23	2.09(2.266)
SeekInfo	4	0.50(0.76)	4	0.36(0.81)
ReadInfo	69	8.63(4.21)	87	7.91(5.75)
Monitor	18	2.25(1.58)	21	1.82(1.94)
Evaluate	24	3.00(2.00)	71	6.73(4.41)
Total	128	16.50(7.56)	206	19.27(12.21)

We further examined whether activation of certain metacognitive events can be linked to students' achievement. We mapped and coded students' behaviors based on the integrated cognitive and metacognitive model for learning (Segedy et al., 2011) and analyzed the learning activities of

the students. We took the frequencies of both user-initiated and metatutor-prompted metacognitive activities. Table 6 shows the frequencies and means (and standard deviations) of the metacognitive events.

A comparison of means showed no significant difference in the number of metacognitive events used by HPK and LPK learners, ( $t(17)=-0.61$ ,  $p>0.05$ ). However, HPK learners showed a high count on *ReadInfo* activities while LPK learners demonstrated high frequencies on both *ReadInfo* and *Evaluate* events.

Regression analysis was used to investigate whether the observed effect of the intervention on the learners' post-test scores was influenced by these metacognitive actions. The test revealed that *ReadInfo* ( $p=0.012$ ), *Monitor* ( $p=0.043$ ) and *Evaluate* ( $p=0.003$ ) significantly correlate to the learning gains of LPK learners. These variables were regarded as possible mediators for pre-posttest learning gains of low ability students. The model equation is  $PT = 1.83 + 0.55ReadInfo - 0.48SeekInfo - 0.08Plan - 0.75Monitor - 0.57Evaluate$ ,  $F(5,5)=8.579$ ,  $r^2=.896$ ,  $p=0.017$ . We failed to find correlates to the learning gains of high ability students;  $F(6,1)=1.190$ ,  $p>0.05$ .

## 6. Discussion and Conclusion

In this study, we extend existing scaffolding research by examining how both cognitive and metacognitive supports, in a learning by teaching ITS for algebra, benefit different types of students, and how learner usage patterns mediate these effects. The data show that both cognitive and metacognitive scaffolding increase learners' achievement. This finding supports the effectiveness of the learning by teaching paradigm in improving students' proficiency in problem solving (Matsuda et al., 2010, Matsuda et al., 2013).

The data also show that metacognitive scaffolding was more beneficial for low prior ability than for high prior ability learners as shown by higher learning gains, which corroborates previous results (Roll et al., 2014). Prior literature has established the importance of prior knowledge for a meaningful and effective learning by teaching exercise. The metacognitive scaffolds compensate for a learner's lack of relevant domain knowledge (Chen & Chou, 2016). Further, metacognitive scaffolding enables students to reflect on the processes involved in problem solving, making students' learning experience more memorable and coherent.

Scaffolding assists students in their learning process. Those who exploit the system's suggestions and assertions approach their tasks systematically and have learned the importance of information seeking activities for a successful learning engagement (Segedy et al., 2013). Ironically, the learners in this study ignored the metatutor's hints, which may have caused the negative learning gains of high ability learners. We hypothesize that the hint avoidance behavior of students could be because of low goal or task commitment, hence they exerted lesser effort in the task by avoiding hints (Linderman et al., 2003). Commitment to set goals is an essential attribute of self-regulated learning (Boekaerts, 1996). Goal commitment directly influenced both students' intention to persist in a task and their actual persistence behavior (Allen and Nora, 1995). The challenge, therefore, is to help students develop not only their cognitive abilities but also their behavioral attributes (e.g. persistence) by helping them become self-regulated learners.

In this study, we found that metacognitive activities *ReadInfo*, *Evaluate* and *Monitor* relate to low prior ability students' learning performance. *ReadInfo*, *Evaluate* and *Monitor* are metacognitive actions that support SRL's process of *reflection* (Siadaty et al, 2016). *ReadInfo*, which pertains to viewing quiz problems' solution, is a metacognitive activity to evaluate one's learning process and compare one's work with others. Besides enacting *ReadInfo*, low prior knowledge learners were also performing actions which allowed them to *Monitor* and *Evaluate* their understanding of the task and the processes they execute to complete the task (Siadaty et al, 2016). *ReadInfo* seemed helpful to students in achieving better performance; however, there were metacognitive events that failed to help low ability students. Actions related to monitoring and evaluating results and processes appeared to be more harmful than helpful in facilitating low ability learners. *Monitor* (e.g. self-explanation), which probes a tutor's reasoning (Kinnebrew and Biswas, 2014), appeared to hurt student learning. In comparison with *ReadInfo*, which is instructive in nature and shows the student what to do, *Monitor* is reflective. Monitoring requires students to think about

their own knowledge and use it to help themselves out of their intellectual rut. If that knowledge is weak in the first place, they may not be able to help themselves. Rather, what they might need is an external intervention to help them move forward. The current software version does not engage students in a dialog to help correct misconceptions; hence, students have no opportunity to learn that their explanation is wrong or to construct deeper knowledge on the subject matter. Thus, there is a need for a constructive feedback mechanism to make self-explanation effective. Moreover, *Evaluate*, which is mapped to the system's Quiz feature, obstructed student learning. We suspect that frequent quizzing disengaged students from the tasks by dissuading students from working on the problem and utilizing the features that could prepare them for the task, a behavior which mirrors "gaming the system" (Baker et al., 2008).

The contingent relationship of metacognition and self-regulation and their impact on student learning (Wagster et al., 2007; Kinnebrew et al., 2014; Duffy and Azevedo, 2015) and task persistence (Pintrich et al., 2000) have been demonstrated in previous studies. Self-regulated learners have the capability to evaluate their tasks, reflect on their performance, and manage their own learning and behavior. They feel empowered to succeed, thus they utilize strategic approaches to complete the tasks successfully and to sustain their efforts when difficulties are encountered. Metacognitive skills activate students' self-regulation, which in turn helps in developing their intellectual curiosity and persistence (Paris and Winograd, 1990). In contrast, the lack of metacognitive abilities may result in task disengagement and a lack of sustained effort to complete the task.

In summary, the findings of this study corroborate previous findings on the effect of tutor learning in the context of learning by teaching as indicated by the learners' improved post test scores. We also found that students' hint avoidance behavior impedes their performance. Furthermore, we found that metacognitive scaffolding led to better learning gains for low prior ability learners. Their performance is mediated by metacognitive activities (i.e. *ReadInfo*, *Evaluate* and *Monitor*), however, metacognitive activities which are related to the reflective process or to the self-monitoring sub-function of self-regulation negatively affect low ability learners' performance.

## 7. Limitations and Future Work

One of the limitations of this study was its small sample size (Metacognitive ( $N = 32$ ) and Cognitive ( $N=35$ )). When grouped according to prior domain abilities, by condition, sample size was reduced further, which limits the generalizability of the findings of this study. The small sample size was due to the high attrition of participants, and the long duration of the study (spanning almost 3 weeks). Also, our data collection coincided with the performance evaluation week of some deployment sites. Given that participation was voluntary, participants gave priority to classroom performance tasks over the experiment, resulting in high attrition. Additionally, we did not collect affect or eye-tracking data in this study. This would have provided evidence for participants' engagement during the ITS use, which would help in making more accurate inferences about the learners' cognitive and metacognitive processes. With no such evidence, we could not confirm whether the participants really paid attention to the resources provided to prepare them for their task as they were utilizing it.

Recent work has emphasized the interdependence of non-cognitive (e.g. critical thinking, self-regulation, persistence) and cognitive skills to prepare students for the increasingly complex nature of 21<sup>st</sup> century jobs. Non-cognitive attributes support cognitive development. Unless closer attention is given to non-cognitive skills, cognitive skills' development may fail. As part of our future work, the authors will conduct further studies to gain a better understanding of how metacognitive learning events affect students' patterns of thoughts and behavior. Action modeling is one potential technique to quantify and detect incidence of non-cognitive factors such as persistence from the interaction logs.

## Acknowledgements

The research reported here was supported by National Science Foundation Awards No. 1643185/1252440. The authors would like to thank Ateneo Laboratory for the Learning Sciences,



Ateneo de Manila University, the Ateneo de Davao University, Krus Na Ligas High School, and the University of the Cordilleras for the support they extended to this study.

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