Jiang, B. et al. (Eds.) (2025). Proceedings of the 33rd International Conference on Computers in Education. Asia-Pacific Society for Computers in Education

Identifying Cognitive and Metacognitive Processes Using Retrospective and Concurrent Think-Aloud Protocols

Rumana PATHAN*, Sahana MURTHY & Ramkumar RAJENDRAN
Centre for Educational Technology, Indian Institute of Technology Bombay, India
*rumana_pathan@iitb.ac.in

Abstract: Think-aloud protocols such as Retrospective Think-Aloud (RTA) and Concurrent Think-Aloud (CTA) are widely used in educational research to examine cognitive and metacognitive processes. RTA captures reflective verbalizations after task completion, often yielding elaborate explanations, while CTA records real-time thoughts, offering direct insights into learners' in-task thinking. Although both protocols uncover complex learning processes, CTA is more commonly used to model metacognition. This study compares RTA and CTA in identifying cognitive and metacognitive processes during problem-solving in MEttLE (Modelling-based Estimation Learning Environment), a computer-based, open-ended learning environment for complex, estimation-based problem solving. We conducted parallel studies using both protocols as learners engaged in estimation problem-solving tasks. The analysis focused on: (1) the overall frequency of verbalizations, (2) the frequency of cognitive and metacognitive processes, and (3) a temporal analysis of metacognitive activity using CTA. Findings show that CTA yielded more on-task verbalizations than RTA. RTA captured high-level control and reflective processes such as model building, estimation reasoning, and adaptive attributions. In contrast, CTA revealed procedural strategies like selecting and adapting learning approaches and gathering context-specific knowledge. CTA also enabled temporal tracking of metacognitive shifts throughout the task. These findings highlight the complementary strengths of both protocols and offer methodological insights for researchers seeking to analyze learners' thinking in technology-enhanced learning environments.

Keywords: Retrospective think-aloud; Concurrent think-aloud; Metacognitive processes; Self-regulated Learning

1. Introduction

Novice learners in computer-based environments engage in cognitive and metacognitive processes such as activating prior knowledge, setting objectives, using strategies, monitoring comprehension, and responding to system-generated prompts to solve complex problems (Azevedo & Wiedbusch, 2023). However, research indicates they often struggle to regulate and monitor learning effectively (Zimmerman, 2013). Identifying these processes is crucial to supporting learners. Among various methods such as human observation, discourse analysis, self-reports, trace data, and neuroimaging, think-aloud protocols remain a preferred approach due to their ability to capture learners' thought processes in real time, offering a rich and nuanced understanding (Vaccaro & Fleming, 2018).

Think-aloud is a simple yet powerful method to reveal complex cognitive processes (Greene et al., 2017; Ericsson, 2006). It captures real-time verbalizations, enabling researchers to interpret learners' cognitive activity as it unfolds. Studies using think-aloud have uncovered processes used by experts like chess masters and doctors (Ericsson, 2006), as well as usability challenges in system design (Alhadreti & Mayhew, 2018). Arguably, it provides the closest representation of spontaneous thought (Greene et al., 2017). Two main think-aloud approaches exist: retrospective (RTA), in which learners verbalize after the task with cues like video playback, and concurrent (CTA), where learners speak within seconds of the thought occurring during the task (Ericsson, 2006). RTA reduces cognitive load during performance but may result in incomplete recall (Birns et al., 2002), while CTA provides real-time data but may strain learners (Greene et al., 2017). Both approaches are widely used in studies on cognitive and metacognitive processes.

The motivation for this research stems from the need to support novice learners who often face challenges regulating cognition during complex, open-ended problem-solving tasks in computer-based environments. While think-aloud protocols are common in metacognitive research, most studies have focused on CTA in simpler tasks like reading, with limited work exploring RTA or applying these methods in complex, dynamic contexts. A critical gap remains in understanding how RTA and CTA differ in capturing the richness, frequency, and temporal dynamics of metacognitive activity (Hertzum, 2024). This study addresses the gap by comparing RTA and CTA in MEttLE (Modelling-based Estimation Learning Environment), a complex, open-ended learning environment in electrical engineering. Using RTA (N=10) and CTA (N=4), we analyzed learner verbalizations coded via Pintrich's SRL framework and MEttLE's pedagogical design across four phases and 17 processes. We compared protocols based on verbalization frequency and the distribution of metacognitive processes. Additionally, we used CTA to demonstrate the temporal flow of metacognitive processes.

2. Literature Review

Metacognition is defined as "knowledge concerning one's own cognitive processes, products, and anything related to them" (Flavell, 1976). It is broadly categorized into two components: knowledge of cognition, i.e., awareness of strategies and cognitive processes, and regulation of cognition, which involves planning, monitoring, and control (Efklides, 2011). While its value in complex problem-solving is well-established, limited research explores how learners actively regulate cognition during such tasks.

The regulation of cognition is closely associated with Self-Regulated Learning (SRL), a framework that encapsulates how learners plan, monitor, and reflect on their learning. SRL is influenced by cognitive, motivational, affective, and metacognitive processes (Panadero, 2017). Several SRL models (e.g., Pintrich, 2000,) detail these processes to varying degrees. Within these frameworks, regulation of cognition is central to achieving learning goals, particularly in complex and open-ended problem-solving scenarios (Krieger et al., 2022).

To understand SRL processes, researchers have used various methods including questionnaires, interviews, observations, eye-tracking, log data, and think-aloud protocols (Greene et al., 2017). Among these, think-aloud protocols are the most widely used, offering real-time access to cognitive and metacognitive processes (Fan et al., 2022). These are typically implemented in two forms: retrospective think-aloud (RTA), where learners reflect post-task, often using screen recordings; and concurrent think-aloud (CTA), which captures verbalizations during task performance (Ericsson & Simon, 1993). Both methods can be analyzed using SRL frameworks, such as Pintrich's (2000), and adaptations suited to digital learning environments (Greene & Azevedo, 2010; Pathan, Murthy, & Rajendran, 2021).

Numerous studies have applied think-aloud protocols to explore SRL. CTA has been used in digital reading (Coiro et al., 2014) and biology learning (Greene & Azevedo, 2010), while Trevors et al. (2014) combined RTA and CTA to identify belief structures. Each protocol has strengths and limitations. CTA provides immediate, unfiltered access to thought processes but may miss unconscious reasoning and impose cognitive load (Jääskeläinen, 2010). RTA offers richer reflection post-task but risks omissions and rationalizations (Birns et al., 2002). To maximize the use of short-term working memory during RTA, use of techniques such as video-stimulated recalls are suggested (Alhadreti & Mayhew, 2018).

To summarize, although both RTA and CTA are valid methods for identifying metacognitive processes, CTA is more commonly used in studies. Each method has context-specific strengths depending on task type and research objective. Most CTA-based research focuses on reading and comprehension tasks, with limited work exploring their use in complex problem-solving and the temporal dynamics of metacognition. Understanding these processes is especially important in open-ended, complex problem-solving tasks where learners need to plan, monitor, and adjust their thinking. This study addresses that gap by comparing RTA and

CTA in an open-ended learning environment (OELE) setting, aiming to inform future research design and protocol selection. The findings will benefit researchers by helping them choose the most appropriate verbal protocol method based on their study goals and task contexts.

3. Research Method

This comparative study investigates how RTA and CTA protocols differ in identifying cognitive and metacognitive processes in learners using a complex problem-solving OELE.

3.1 Participants and Setting

Fifteen undergraduate engineering students (ages 20–21) from a private institute in a tier-2 city in India participated in this study. Seven were from mechanical engineering and eight from electronics and telecommunication, with a gender distribution of five females and ten males. Five students (1 female, 4 males) were assigned to the concurrent think-aloud (CTA) group, and ten (4 females, 6 males) to the retrospective think-aloud (RTA) group; however, one male CTA participant's data was excluded due to technical issues. All participants provided informed consent and received cash compensation for their participation in the study. The study was reviewed and approved by the Institute Ethics Committee at IIT Bombay, India.

Participants interacted with MEttLE on desktop computers with 23-inch screens. MEttLE was locally hosted on a machine via port 8080, with learners accessing it through a static IP over LAN. Interaction data including timestamp, object ID, log data, page ID, and session ID was recorded on a local MongoDB server (Pathan, Shaikh & Rajendran, 2019). Verbal and screen data were captured using OBS Studio for both CTA and RTA sessions. Additionally, handheld recorders were used during RTA interviews to capture audio.

3.2 Learning Environment and Procedure

MEttLE (Modelling-based Estimation Learning Environment) is an OELE designed to support novice learners in estimation-based problem-solving tasks (Kothiyal & Murthy, 2010). Learners solve problems such as estimating the motor power of a racing car using parameters like wheel diameter, distance, and weight. The system scaffolds both cognitive and metacognitive processes through structured tasks, expert guidance, and reflective prompts.

Problem-solving in MEttLE involves five interconnected tasks: functional, qualitative, and quantitative modelling, followed by calculation and evaluation. Learners define system operations, identify relationships among entities, develop equations, make assumptions, perform calculations, and evaluate their solutions. Being open-ended, MEttLE allows flexible sequencing and iterative exploration. Key tools include a simulator, calculator, info center, scribble pad, causal map builder, equation builder, and problem map, along with hints and prompts to support strategic thinking.

In the RTA protocol, learners engaged in a 60–90 minute problem-solving session, after which they participated in a stimulated recall interview. Using their session recordings, they were asked open-ended questions such as "What were you thinking while watching the tutorial video?" to prompt reflection on their cognitive processes. In the CTA protocol, learners first practiced thinking aloud with a warm-up task (e.g., long multiplication) before solving the same estimation problem in MEttLE while verbalizing their thoughts in real time. Researcher interaction was minimized, limited to neutral prompts like "keep talking." The think-aloud verbalizations and interaction with MEttLE were recorded in a video format and transcribed.

4. Coding and Data Analysis

4.1 Coding of Think Aloud Protocols

The transcribed retrospective and concurrent think-aloud protocols were analyzed using a coding mechanism that links learner verbalizations to observable indicators, each corresponding to a specific metacognitive process and phase (Pathan, Singh, Murthy & Rajendran, 2022). This scheme draws on Pintrich's (2000) SRL framework and the pedagogical design of MEttLE (Kothiyal & Murthy, 2018). It comprises four phases - Planning & Activation, Monitoring, Control & Regulation, and Reaction & Reflection, encompassing 17 metacognitive processes (e.g., target goal setting, feeling of knowing), and their indicators. Each phase represents a distinct dimension of metacognitive regulation. Phase 1 (Planning & activation) focuses on goal setting and activating prior knowledge; Phase 2 (Monitoring) captures metacognitive awareness such as the feeling of knowing; Phase 3 (Control & regulation) involves selecting and adapting cognitive strategies; and Phase 4 (Reaction and reflection) includes learners' evaluations and reflections on their task performance.

For example, when a learner articulates a plan or goal such as deciding to complete a task first, it is coded under the indicator "Learner may begin a task by setting specific goals for learning," which falls under the Target Goal Setting process within the Planning & Activation phase. Similarly, if a learner expresses uncertainty but believes they know the answer (e.g., *"I can't remember the exact value, but I know it was discussed"*), this maps to the indicator "Learner cannot recall something... but has strong feelings they know it," representing the Feeling of Knowing process in the Monitoring phase. Another example is when a learner uses the scribble pad to visually represent a model, which corresponds to the indicator "Learner uses scribble pad" under the External Representation process in the Control & Regulation phase. These examples illustrate how specific learner behaviors are systematically categorized to reveal the metacognitive processes and phases involved in problem-solving.

4.2 Data Coding and Analysis

Table 1 presents example excerpts from both RTA and CTA protocols alongside their corresponding codes. One RTA example, *"I selected mass and increased the parameters with velocity, and then I compared where it is varying and found the maximum change"*—was interpreted using the screen recording, which showed the learner interacting with the simulator. Here, the learner held the mass constant and varied the velocity to observe its effect on power, thereby employing a one-variable-at-a-time strategy to explore system dynamics. This behaviour was mapped to the process of 'model building' under the phase 'control and regulation'. Similarly, a CTA example, *"I do not understand this. Does it mean I can create a causal map of my own?"* was observed after the learner read a prompt related to causal map creation within the qualitative model-building subgoal. This statement reflects metacognitive monitoring, as the learner questions their understanding, aligning with the process of 'judgement of learning and comprehension monitoring' under the 'monitoring' phase.

Table 1. *Example excerpts from RTA and CTA protocol, the context obtained from the screen recordings, and the codes.*

	Excerpt	Context	Indicator	Process	Phase
RTA	*Okay, now I will have to find power*	Read problem statement	Learner begins a task by setting a specific goal.	Target goal setting	Planning & activation
	The idea was not so clear; given a question, I could not get the exact idea about the approach.	Problem map	Learner becomes aware that he does not understand something	Judgement of learning	Monitoring
	I selected mass and increased the parameters with velocity, and then I compared where it is varying and then found the maximum change	Simulator	Learner uses variable manipulation, with implicit guidance to incorporate problem context in the estimation process	Model building	Control & regulation

	The question forced me to think whether the option we selected was correct or not.	Qualitative model evaluation	Learner uses question prompts to reflect on (problem-solving) process	Productive reflection on process	Reaction and reflection.
CTA	*How should I begin? Okay, let me calculate the maximum value first.*	Functional model	Learner begins a task by setting a specific goal.	Target goal setting	Planning & activation
	I do not understand this. Does it mean I can create a causal map of my own?	Causal map builder	Learner becomes aware that he does not understand something	Judgement of learning	Monitoring
	I think Pramod[1] is wrong because certainly, for a 10 kg toy car, it requires 10W, but we do not know the specifications.	Evaluation	Learners use question prompts to do estimation reasoning	Estimation reasoning	Control & regulation
	I think for now I am going in the right direction	Qualitative model evaluation	Learner evaluates his performance.	Cognitive judgement	Reaction & reflection.

5. Results

We coded 1698 RTA (N=10) and 2011 CTA (N=4) verbalizations, averaging ~170 and ~503 per learner, respectively. Analyses focused on (1) frequency of verbalizations and phases, (2) frequency of key processes (excluding those with average <2), and (3) temporal patterns of phases in CTA.

5.1 Frequency of Verbalizations and Phases

The average frequency of verbalizations was higher in CTA (503) compared to RTA (170). In RTA, 57% of the verbalizations (approximately 97 per learner) were on-task and mapped to one of the four metacognitive phases, while the remaining were not on-task. In contrast, 92% of CTA verbalizations (about 463 per learner) were on-task. These findings indicate that CTA not only yields a greater volume of verbal data but also a higher proportion of relevant, on-task verbalizations compared to RTA, aligning with existing literature discussed earlier.

Figure 1 illustrates the average frequency of phases (namely, planning & activation, monitoring, control & regulation, and reaction & reflection) per learner in both RTA and CTA protocol analyses, along with the percentage distribution of each phase in the two protocols. For instance, in the RTA protocol, learners deployed the planning and activation phase approximately 30 times, and this phase accounted for 30.6% of all phases. We found that, the phase of 'control & regulation' was the most frequently used phase in both CTA (78.8%) and RTA protocol (31.3%) analyses, surpassing the other phases in terms of frequency. However, both RTA and CTA exhibit a nearly identical occurrence of verbalizations in the planning & activation, monitoring, and reaction & reflection phases.

[1] Pramod is the name of a fictitious person used in a question prompt, specifically designed to help learners compare and evaluate their estimated value of power.

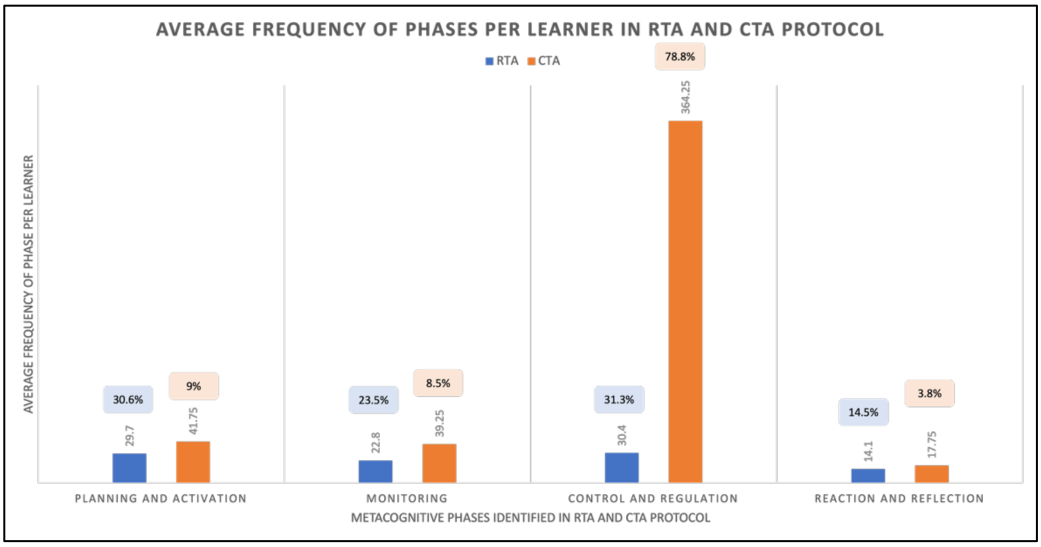

Figure 1. The average frequency of phases per learner in RTA and CTA protocol analysis.

5.2 Frequency of Processes

Due to the disparity in frequencies between the control and regulation phase and the other phases, we conducted a frequency analysis of the processes and divided the results into two subsections. 1) the difference between the average frequency of processes in the 'control & regulation' phase and 2) the difference between the average frequency of the processes in the 'planning & activation', 'monitoring', and 'reaction & reflection' phases.

5.2.1 Processes in the phase control and regulation

Figure 2 gives us a deeper insight into the type of specific processes represented in Control & Regulation phase in the two protocols. The average frequency of all processes per learner is higher in the CTA protocol than in the RTA protocol. However, the relative percentage distribution of some processes is higher in the RTA protocol. For example, learners in RTA verbalize statements that indicate problem-solving processes such as 'model building' (52.7%) and 'estimation reasoning' (28.4%) more frequently than other processes. Conversely, CTA verbalizations indicate a comparatively higher frequency of procedural processes such as 'selection and adaptation of control strategies' (30.5%) and 'gather context-specific knowledge' (44.7%) as compared to 'model building' (16.3%) and 'estimation reasoning' (8.4%).

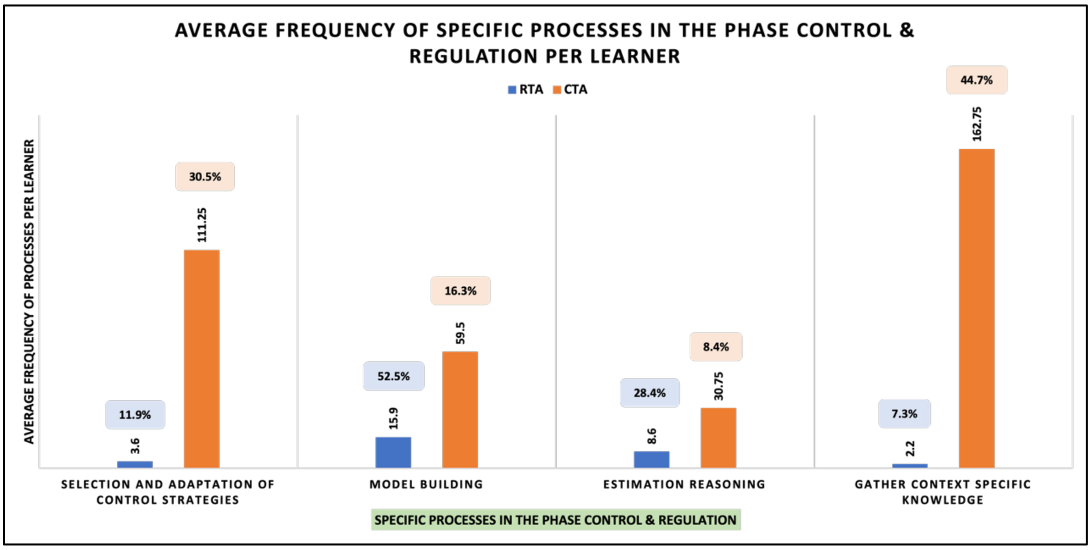

Figure 2. The average frequency of processes in the phase control and regulation in RTA and CTA protocol analysis

The procedural processes of selecting and adapting control strategies and gathering context-specific knowledge showed distinct patterns across the two protocols. In CTA, commonly observed indicators for strategy adaptation included re-reading, paraphrasing, and summarizing text—actions primarily aimed at enhancing comprehension and retention. Additionally, learners employed specific problem-solving strategies such as sequencing subgoals, identifying relevant information sources, and interpreting visual inputs like animations and graphs. In contrast, RTA captured only these problem-solving strategies, without the broader range of comprehension-related behaviors seen in CTA. For the process of gathering context-specific knowledge, CTA learners frequently accessed information embedded in prompts and hints, while RTA learners primarily referred to the infocenter.

The problem-solving processes of model building and estimation reasoning exhibited similar indicators in both RTA and CTA protocols. In both cases, learners engaged in model building by manipulating variables in simulations, using fictive motion language, constructing causal maps, and arranging relevant parameters and equations. Likewise, estimation reasoning was evident as learners in both protocols verbalized their use of question prompts and hints to support their estimations.

5.2.2 Processes in the phase – planning & activation, monitoring, and reaction & reflection

Figure 3 shows the average frequency of all processes within the phases of (a) planning & activation, (b) monitoring, and (c) reaction & reflection. Across these phases, most processes appeared more frequently in CTA than in RTA, with the exception of 'adaptive attributions', which occurred about five times per learner in RTA but was absent in CTA. Conversely, processes such as 'target goal setting', 'activation of relevant prior content knowledge', 'judgement of learning and comprehension monitoring', and 'cognitive judgements' were slightly more frequent in the CTA protocol.

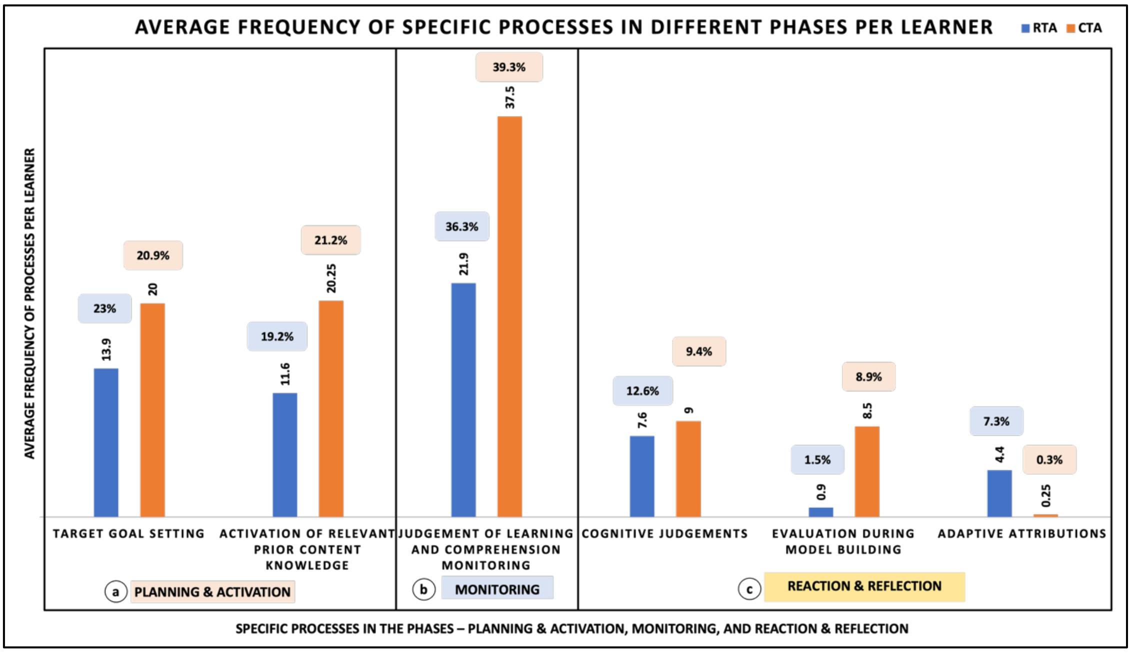

Figure 3. The average frequency of processes in the phases a) planning & activation, b) monitoring, and c) reaction & reflection phase in RTA and CTA protocol analysis

In the Planning & Activation phase, learners in both RTA and CTA protocols demonstrated the process of target goal setting by articulating specific goals related to learning, time management, and performance expectations. These goals were not fixed; learners revised them as they progressed through the task and expressed their evolving intentions using planning-related prompts. Both groups also engaged in activating relevant prior content knowledge, but they did so differently. RTA learners typically accessed prior knowledge by recalling information from memory. In contrast, CTA learners adopted a more deliberate approach, actively using prompts and self-questioning strategies to refine their understanding and construct a more accurate representation of the problem.

Within the Monitoring phase, the process of judgement of learning and comprehension monitoring was evident in both protocols. Learners identified moments of clarity or confusion in their understanding, sometimes questioning the task (e.g., *"If I increase the acceleration at this point, what will be the velocity?"*) to check comprehension. In both RTA and CTA, learners used verbal statements triggered by question prompts to monitor and evaluate their ongoing understanding of the task.

In the Reaction & Reflection phase, learners engaged in cognitive judgments by evaluating their own performance. The process of evaluation during model building was observed when learners reflected on their models using evaluation and contextualization prompts. While both protocols captured this behaviour, it appeared more frequently in CTA. In contrast, adaptive attributions—where learners attributed success or failure to internal factors (e.g., effort) or external influences (e.g., poor strategies)—were more commonly verbalized in RTA, suggesting a reflective, post-task orientation more suited to retrospective reporting.

5.3 Temporal Patterns of Phases in CTA.

One significant methodological advantage of the CTA protocol over RTA is its ability to capture the temporal nature of metacognitive activity. Because CTA involves immediate verbalization of thoughts during task performance, it allows researchers to track the timing and sequence of metacognitive processes—something not possible with RTA. Figure 4 illustrates the average frequency of four metacognitive phases—planning & activation, monitoring, control & regulation, and reaction & reflection—over a 120-minute problem-solving session in an OELE. To analyze trends over time, the session was divided into 12 intervals of 10 minutes each. For example, in the first interval (0–10 minutes), learners engaged in planning & activation 11 times out of 170 total metacognitive events (6.47%) and in control & regulation 132 times (77.65%). Overall, learners used control & regulation strategies most frequently—about three times per minute—while planning & activation and monitoring occurred roughly once every three minutes, and reaction & reflection once every seven minutes.

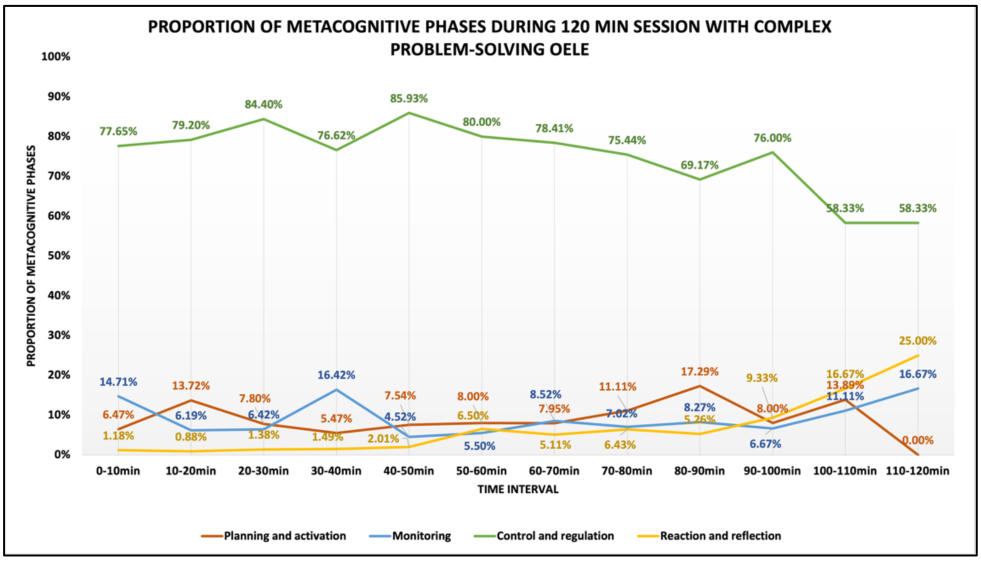

Figure 4. The proportion of metacognitive phases every 10 minutes in CTA protocol analysis

The temporal distribution of phases reveals several patterns. Control & regulation dominated the early to mid-stages of the session, peaking at 85.93% between 40–50 minutes and tapering to 58.33% by the session's end. Planning & activation was used consistently, with a peak of 17.29% at 80–90 minutes, but dropped to 0% in the final 30 minutes. Monitoring was most visible at the beginning (0–10 mins and 30–40 mins) and showed a gradual increase, peaking at 16.67% near the end. Reaction & reflection was the least used initially (below 2%

in the first 50 minutes) but rose steadily, reaching a high of 25% in the final 10 minutes. These patterns suggest a shift in learners' metacognitive engagement—from strategic planning and control in the early stages to increased evaluation and reflection as the session progressed.

6. Discussion and Conclusion

The analysis reveals that learners using the CTA protocol verbalized their thoughts more frequently than those using RTA. CTA participants often reported all thoughts, including procedural actions like re-reading and paraphrasing, while RTA learners tended to omit such details, focusing instead on strategies they perceived as significant—such as interpreting simulator graphs. This aligns with earlier comparisons of RTA and CTA in usability studies (Birns et al., 2002). Our study contributes to the limited body of research comparing these protocols in the context of metacognition, especially in complex, open-ended learning tasks.

Both protocols were effective in identifying cognitive and metacognitive processes within the phases of planning & activation, monitoring, and reaction & reflection. The key difference was in the control & regulation phase, which appeared more frequently in CTA. This is likely because CTA captures in-the-moment actions without filtering, including unproductive steps, while RTA, being retrospective, leads learners to report only those actions they found meaningful. Additionally, CTA and RTA differed in the indicators of processes such as control strategy adaptation, context-specific knowledge gathering, prior knowledge activation, and adaptive attributions—the latter more common in RTA due to its reflective nature.

By capturing these distinctions, the study addresses a critical gap in the literature: understanding how RTA and CTA differ in capturing the richness, frequency, and temporal characteristics of metacognitive activity during complex problem-solving. The temporal data from CTA revealed how metacognitive engagement evolved across the session—control & regulation dominated early stages, while reaction & reflection peaked near the end. These patterns support SRL theory (Greene & Azevedo, 2010) and demonstrate CTA's value in uncovering temporal shifts that are otherwise inaccessible through RTA.

To conclude, this study investigated the differences between applying RTA and CTA protocols to analyze learners' cognitive and metacognitive processes while interacting with a complex problem-solving learning environment. Data were collected from 10 RTA and 4 CTA participants using MEttLE, an OELE designed for engineering estimation tasks. The verbalizations were coded using a mechanism grounded in Pintrich's SRL framework and MEttLE's pedagogical design, and the protocols were compared based on the frequency of metacognitive phases—planning & activation, monitoring, control & regulation, and reaction & reflection—and their associated processes. However, several limitations must be acknowledged. The small sample size limits the generalizability of our findings, although approximately 3700 verbalizations were collected, providing rich data for analysis. We did not explore the influence of learner personality, and the temporal characteristics of metacognitive phases may vary across different learning contexts. Some metacognitive processes, like model building, are specific to estimation tasks in MEttLE and may not transfer to other domains. Furthermore, the lab-based setup may have influenced learner behaviour, and the study focuses solely on overt indicators of metacognition, potentially missing more implicit cognitive activity. To address these limitations, future work will increase the sample size, consider learner characteristics, and incorporate tools like eye-tracking to enhance retrospective protocols beyond screen recordings (Paikrao et al., 2025).

Acknowledgements

We gratefully acknowledge Dr. Aditi Kothiyal, the participants, and the research team at IIT Bombay for their invaluable support and contributions to this study.

References

Alhadreti, O., & Mayhew, P. (2018, April). Rethinking thinking aloud: A comparison of three think-aloud protocols. In Proceedings of the 2018 CHI conference on human factors in computing systems.

Azevedo, R., & Wiedbusch, M. (2023). Theories of metacognition and pedagogy applied to AIED systems. In Handbook of artificial intelligence in education (pp. 45-67). Edward Elgar Publishing.
Birns, J. H., Joffre, K. A., Leclerc, J. F., & Paulsen, C. A. (2002, July). Getting the whole picture: Collecting usability data using two methods—-concurrent think aloud and retrospective probing. In Proceedings of UPA Conference (pp. 8-12).
Coiro, J., Knobel, M., Lankshear, C., & Leu, D. J. (Eds.). (2014). Handbook of research on new literacies. Routledge.
Efklides, A. (2011). Interactions of metacognition with motivation and affect in self-regulated learning: The MASRL model. Educational psychologist, 46(1), 6-25.
Ericsson, K. A. (2006). Protocol analysis and expert thought: Concurrent verbalisations of thinking during experts' performance on representative tasks. The Cambridge handbook of expertise and expert performance, 223-241.
Ericsson, K. A., & Simon, H. A. (1993). Protocol analysis (revised edition). Overview of methodology of protocol analysis.
Fan, Y., van der Graaf, J., Lim, L., Raković, M., Singh, S., Kilgour, J., ... & Gašević, D. (2022). Towards investigating the validity of measurement of self-regulated learning based on trace data. Metacognition and Learning, 17(3), 949-987.
Flavell, J. H. (1976). Metacognitive aspects of problem solving. The nature of intelligence.
Greene, J. A., Deekens, V. M., Copeland, D. Z., & Yu, S. (2017). Capturing and modeling self-regulated learning using think-aloud protocols. In Handbook of self-regulation of learning and performance (pp. 323-337). Routledge.
Greene, J. A., & Azevedo, R. (2010). The measurement of learners' self-regulated cognitive and metacognitive processes while using computer-based learning environments. Educational psychologist, 45(4), 203-209.
Hertzum, M. (2024). Concurrent or Retrospective Thinking Aloud in Usability Tests: A Meta-Analytic Review. ACM Transactions on Computer-Human Interaction, 31(3), 1-29.
Jääskeläinen, R. (2010). Think-aloud protocol. Handbook of translation studies, 1, 371-374.
Kothiyal, A., & Murthy, S. (2018). MEttLE: a modelling-based learning environment for undergraduate engineering estimation problem solving. Research and practice in technology enhanced learning.
Krieger, F., Azevedo, R., Graesser, A. C., & Greiff, S. (2022). Introduction to the special issue: the role of metacognition in complex skills-spotlights on problem solving, collaboration, and self-regulated learning. Metacognition and Learning, 1-8.
Munshi, A., & Biswas, G. (2019, June). Personalisation in OELEs: developing a data-driven framework to model and scaffold SRL processes. In International Conference on Artificial Intelligence in Education (pp. 354-358). Springer, Cham.
Paikrao, A., Nath, D., Rajendran, R., & Mitra, R., (2025). Enhancing Retrospective Think-Aloud Protocols with Eye-Gaze data. In B. Jiang et al. (Eds.), Proceedings of the 33rd International Conference on Computers in Education. Asia-Pacific Society for Computers in Education.
Panadero, E. (2017). A review of self-regulated learning: Six models and four directions for research. Frontiers in psychology, 8, 422.
Pathan, R., Murthy, S., & Rajendran, R. (2021, November). A coding mechanism for analysis of SRL processes in an open-ended learning environment. In International Conference on Computers in Education.
Pathan, R., Shaikh, U., & Rajendran, R. (2019, December). Capturing learner interaction in computer-based learning environment: design and application. In 2019 IEEE Tenth International Conference on Technology for Education (T4E) (pp. 146-153). IEEE.
Pathan, R., Singh, D., Murthy, S., & Rajendran, R. (2022, June). Identifying Metacognitive Processes Using Trace Data in an Open-Ended Problem-Solving Learning Environment. In International Conference on Intelligent Tutoring Systems (pp. 213-226). Cham: Springer International Publishing.
Pintrich, P. R. (2000). The role of goal orientation in self-regulated learning. In Handbook of self-regulation (pp. 451-502). Academic Press.
Trevors, G., Duffy, M., & Azevedo, R. (2014). Note-taking within MetaTutor: Interactions between an intelligent tutoring system and prior knowledge on note-taking and learning. Educational Technology Research and Development, 62(5), 507-528.
Vaccaro, A. G., & Fleming, S. M. (2018). Thinking about thinking: A coordinate-based meta-analysis of neuroimaging studies of metacognitive judgements. Brain and neuroscience advances, 2, 2398212818810591.
Zimmerman, B. J. (2013). Theories of self-regulated learning and academic achievement: An overview and analysis. Self-regulated learning and academic achievement, 1-36.