Metacognitive Planning and Monitoring: 9th Graders Performing a Long-Term Self-Regulated Scientific Inquiry in a Complex System

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Abstract: A comprehensive daily-report instrument supplying metacognitive prompts was used to promote a high-achieving group of 5 ninth graders' collaborative planning, execution, monitoring, and adjustment of a long-term, open-ended ecological inquiry about a live ecosystem (greenhouse). Prompts guided the group's discussion and documentation of each laboratory session's planned and executed behaviors, aiming to trigger students' metacognitive cues about gaps and progress along the yearlong project. Fine-grain analysis of session transcripts, students' written documentation, and videotapes for this single group case yielded a recurrent pattern of within-session behavior and evidence for the group's use of metacognitive knowledge and skills over time as well as salient difficulties. Discussion focused on the role of specific components in this student centered self-regulated long-term learning environment – the daily reports, the teachers, and the live ecology inquiry context. Implications were discussed for future research and long-term inquiry-driven science education design.

Major Issues Addressed

The present study addresses metacognitive planning and monitoring, using a specially designed prompt for enhancing learners' Metacognitive Awareness (MA) while performing a long-term, authentic open inquiry of live complex ecosystems, in an environment of full personal and academic autonomy. Such an environment has the potential to activate metacognitive knowledge (Chinn & Hmelo-Silver, 2002), overcome some inherent difficulties and develop MA (Eilam, 2002; Eilam & Aharon, 2003). The present study examined learners' real-time on line MA while planning a complex long-term yearly ecosystems inquiry, executing these plans, monitoring outcomes in light of set goals and adjusting thoughts and actions. Metacognitive prompts (DPSRI – Daily Planning Self-Report Instrument) were provided for facilitating a case group of high-achieving 9th graders' metacognition as evidenced through their observed verbalizations, behaviors and written self-reports.

Potential Significance of the Study

Thus far, metacognition and monitoring have been mostly examined in shorter computer-based simulations. The present environment of a long-term inquiry enables the on line fine-grain studying of MA due to the continuous, dynamic, and interactive process of thinking and rethinking that involves flexibility, judgment, and metacognition, applied in response to changes occurring in the researched system. I also suggest a novel prompt/tool for promoting, scaffolding, and studying MA, planning and monitoring. Presented on paper, the Daily Planning Self-Report Instrument (DPSRI) scaffolds learners' MA. Last, although planning is a core element in metacognition, knowledge about students' planning is deficient.

Theoretical and Methodological Approaches

Rooted in the constructivist and sociocultural perspectives, a group case study method was selected to investigate students' MA. A case is a specific, complex, functioning, well-bounded, integrated system, characterized by patterned consistent behavior that is clearly differentiated in some of its features from other systems (Stake, 1995).

Participants

The single distinct group (one of eight in the classroom) of 5 high-achieving and motivated ninth graders (two girls and three boys), performed the ecological inquiry collaboratively with the final distant goal of producing a scientific report of their research. The group was unique in its composition and in its personal and social boundaries, distinct patterns of interactions and collaboration, and their different inquiry boundaries. No roles were assigned and no persistent "leaders" emerged. Because MA is related to domain knowledge (Alexander et al., 2011) this high achievers group was expected to provide a worthwhile case for analysis of students' MA.

The Learning Context

<u>Laboratory Schedule and Physical Layout</u>

The inquiry was performed over 30 sessions, in weekly session of 3 hours (including breaks), in the school science laboratory. The group occupied one table of the 10 contained in the lab. Students collaborated on the

DPSRI. Students built two greenhouse ecosystems (control and experiment). Members had to learn about their selected ecosystem and its components, formulate a broad topic of interest, focus gradually on possible research questions, raise hypotheses based on their knowledge of ecology and biology, choose one hypothesis for examination in their greenhouse, and select its biotic and abiotic components. The case group examined the "greenhouse effect" by increasing the CO_2 amounts and measuring the system varied variables (e.g., temperature, number and behaviors of organisms and related processes.) Initially, the group collected a set of all possible measures from both the experimental and control systems (e.g., organisms' size and weight; plants' number of leaves; bacteria samples from the soil, air, and leaves; temperature; pH) over a 1-month period. Students designed their own representations like tables, graphs, and drawings to document the lengthy data collection. Then, the group introduced CO_2 from a special container into the "experimental" system only. Students cared for their systems, collected and processed data, generated conclusion and submitted a written report.

Student Autonomy

In order to enable students' free planning and managing of the inquiry, the onus of responsibility was shifted entirely onto students to plan, perform, and manage their long-term inquiry as they saw fit, after considering possible alternatives and choosing among them according to self-determined goals and resources. Group members were granted complete autonomy over their behavior, including decisions regarding taking breaks, coming to sessions, or homework. Students were never reprehended for anything but disrupting a classmate's learning. They had to present their research in a school conference and submit a final written scientific report.

Support Mechanisms

Students have never experienced such a lengthy SR project, and teachers' external feedback about the quality of regulation and the inquiry performance were mostly avoided to enable their autonomic decisions. Therefore, support and scaffolding of MA were provided as: *(a)* The DPSRI (see below) including practice of its use and a textbook about inquiry and its skills; *(b)*Teacher guidance; *(c)* Theoretical courses in ecology, taught traditionally and concurrently with the 3 weekly laboratory hours; *(d)* Students' files.

Scaffolding Tools to Provide Metacognitive Prompts

Prompts were developed based on literature concerning SRL, prompts, cues and metacognition. It required learners' continuous real-time reporting about their performance in each session and enabled calibration of thoughts and behaviors by planning and monitoring plans execution. *Planning.* Planning is intentional, promotes goal attainment under specific circumstances, enhances performance, allows for anticipation of consequences by generating external representations of future behavior prior to enactment, which guides future planning in similar situations, prevents some mistakes, and involves the employment of metacognition to transform learning intentions into action plans. Planning is enhanced by a less structured environment (Jordan, Ruibal-Villasenor, Hmelo-Silver, & Etkina, 2011), but is particularly difficult in it because of the unknown variables and the uncertainty about actions' results (Allen, Hendler, & Tate, 1990). Concrete and attainable goals are set following the examination of the task's features (on-going inquiry) and serve as proximal regulators that emerge from the decomposition of distal goals. The initialization of relevant actions is ensured by selecting a set of activities, determining their enactment order, and coordinating these actions to achieve the stated goals. Planning involves awareness of one's own metacognitive knowledge and resource allocation (e.g., time, space, equipment) while considering the affordances and constraints of the specific circumstances, as well as the efforts that need to be invested to attain the goal (Gollwitzer, 1996; Prins, 2002; Ward & Morris, 2005). ***Monitoring*.** If execution of plans is not monitored, evaluated, and revised accordingly, no change in behavior would be possible. Metacognitive monitoring enables control and management over the effectiveness of learners' executed actions and cognition that may affect behavior. Monitoring activity relies on learners' ability to perceive internal and/or external cognitive, affective, and/or situational cues (Carver & Scheier, 1990). Perceived cues are triggered by comparisons between current and goal state and constitute feedback that initiates learners' MA, which in turn produces a behavior to reduce perceived gaps by changing plans or parts of them. *Time management.* Time management is a core component of planning and monitoring and is subjectively experienced; students' diverse time orientations may shape their mode of engagement with tasks (Duncheon & Tierney, 2013). Very little has been published on this issue as related to scientific inquiry. During a long-term, complex process of inquiry, time constraints call for increased efficiency and require making metacognitive decisions concerning choices among alternative actions and time management. Cues suggesting an unexpected rate of progression toward goals may influence planning.

The Daily Planning Self-Report Instrument – DPSRI

Completion of the DPSRI included (see Figure 1): (a) Reporting concrete, limited goals that could be achieved during the session; (b) Reporting suggested plans in the "suggested plan" column, by: (i) selecting and describing context-dependent, accurately defined activities (e.g., to read about the frog) and categorizing them using the ready activity segment labels pool (e.g., gathering information); (ii) determining the sequence of activity execution; (iii) allocating time to each activity; and (iv) determining the setting for performing the activity (e.g., cooperatively, individually); (c). Reporting enacted performance: Students completed the "enacted plan" column separately for each planned segment, immediately after its execution to decrease cognitive load and increase accuracy of reporting. These "enacted" reports included the recording of (i) the performed activity's description and segment label, (ii) their actual sequencing, (iii) their duration, and (iv) the work setting used; (d). Assigning homework.

DAILY PLANNING SELF-REPORT **Student Name:** Tim **Group:** White **Date:** January 24
Session Goals: Complete the principles and raise a research question

Hour	SUGGESTED PLAN				ENACTED PLAN			
	Activity description	Segment label	Time allocated	Setting	Activity segment	Segment label	Time used	Setting
8:15	Planning	Completing the DPSRI		Group	Ask the teacher about the Temp.	Information gathering		Group
8:25	Talk to the technician	Technical		Indiv.				
8:35	Measuring	Technical: Taking care of system		Group	Caring for the biotic,	Technical: Taking care of system		Group
8:45		Information gathering: Collecting data			Planting plants			

Figure 1. An Example of The Daily Planning Self-Report

The DPSRI self-report differs from other instruments in several key features that increase its validity and achieve additional benefits: (a) *Activity description and categorization using a pool of ready segment labels*, for increasing objectivity and creating a uniform "language" of self-reporting, which facilitated student comparisons between the planned and enacted columns within a session as well as comparisons of reports between sessions, thereby enabling cue input and monitoring of plan effectiveness, promoting MA. In addition, this uniformity and objectivity increased coders' inter-judge agreement; (b) *Reporting on-line of enacted activities immediately following their completion,* rather than after the entire 3-hour session, thus reducing the effect of cognitive load and increasing reporting accuracy; (c) Legitimacy of reporting any enacted activity, *thus reducing social desirability*; (d) *Monitoring planned-enacted identified gaps, thus providing evidence of MA.* Because reasoning about gaps causes and making decisions regarding necessary future behavioral changes, is difficult and require MA, changes in planning along the year may be indicative of MA and enables deepened insight into students' behaviors. In addition, successful enactment must account for past similar experiences and may even include monitoring through the examination of previous DPSRIs. The intrusiveness involved in externalizing students' actual behaviors probably also influenced such behaviors by increasing MA of certain planning and time management elements. A 90% inter-rater reliability while rating 20% of the reports was accepted.

Data Collection and Analysis

Group's working modes and interactions over the year were recorded by a video camera and discourses were fully transcribed. Data were analyzed from these transcripts and members' completed DPSRI and videotapes were consulted in cases of ambiguity. Transcript analysis focused on utterances related to the DPSRI, which yielded ample evidence on students' MA.

Identifying the Group's Content and Sequence of Work Patterns

The aggregated selected utterances were repeatedly read by two experts in biology and in learning and were scrutinized for internal consistency regarding the group's work patterns over the year as related to completing the DPSRI. Central student activities were identified in their chronological order in each single session, and then activity sequences were compared between sessions (inter-judge agreement of 86% regarding the group's behavioral pattern). Work pattern showed very few deviations despite changing contexts.

Report Analysis

The written DPSRI materials were read carefully by the same two judges to identify explicit direct and indirect evidence of students' MA, as manifested by their planning, gap monitoring, reasoning about those gaps, and adjustments of subsequent plans. The DPSRIs were analyzed within and across the predetermined phases of self-reporting (i.e., goals, suggested plans, enacted performance, and assigning homework). Reports were analyzed within each single session, and changes in behaviors were traced across sessions (83% inter-judge agreement).

Major Findings, Conclusions, and Implications

Group Behavioral Pattern

Overall, a consistent 4-part pattern emerged: (a) *Preparations for planning*: Browsing through the inquiry textbook and examination of the systems to decide what needed to be done (e.g., exercises) and be studied (e.g., ecology knowledge). (b) *Collaborative planning and recording plans in the DPSRI.* After planning, students copied from each other plans to yield identical reports. They filled the goals supported by the inquiry textbook ("We saw what we have to do. We have to gather materials to focus the topic onto a limited subject for inquiry"), and the suggested plan column by discussing activity segments and settings but rarely arguing about time allocation. Categorization of activities into label segment was acquired over few sessions. Initially, planning was mostly intuitive, based on past experiences and school habits and norms rather on monitoring. Around the fifth session students exhibited MA probably evolving from perceiving DPSRI cues. Time pressures were explicitly expressed and affected planning. (c) *Enacting plans*: Students reminded each other to fill in this column after completing each activity. ("G: Wait, before you go out, report the enacted. R: Right, let's fill out the daily report.") Most sessions' discourse exhibited students' implicit comparisons between the planned and enacted, evidencing students' perception of metacognitive cues (D: "We're behind, look at the yearly report. T: But the whole idea is that you move forward in the inquiry at your own pace."). They verbally expressed their perceived results of such comparisons (time lags, gaps in activities), and tried to repair them by changing plans. From the eighth session on, they accepted gaps as inevitable but monitored their thinking and progress in attempt to improve future plans. Some activities (reading and exercises) were always enacted individually, whereas inquiry related activities were performed in collaboration. To save time students frequently performed different activities in parallel within the same activity segment.

Group Written Reports Over Time: Metacognitive Awareness

To reveal MA as manifested by students' written reports, the DPSRIs were compared and analyzed over time. Because their reports were almost identical only one of them was examined. Findings are presented according to the DPSRI phases, indicating what can be construed as MA for each.

(**a**). *Setting proximal goals*. MA was evidenced in realistic, relevant, logically sequenced goals that could be operationalized. These were usually related to structured and linear tasks (e.g., to gather specific information). Ill-structured tasks resulted in general goals (e.g., design the experiments) that impeded students' ability to enact plan successfully. From midyear on, goals demonstrated increased MA of situational factors (e.g., time) and future group need (e.g., devoting a lesson for fixing the system). (**b**) *Suggested and enacted plans*. MA was evidenced in the accurate definition of easily applicable and limited scope activities that were almost always categorized correctly to the general segment labels and by students' added new customized segments according to identified needs. Planned-enacted gaps initiated MA monitoring, and identification of the problem that caused it expressed in the enactment of an unplanned segment; changing break time to be after a discussion was completed because "a discussion after we come back is never the same"; or inserted unplanned "teacher consultations" after being aware of their lack of understanding during a planned discussion. (**c**) *Allocating time resources.* MA was evidenced in students' comments about a temporal gap and along time. For example, when too many activities were previously planned for a particular time unit, they reduced them in the following plans, when plans did not include break to save time and students felt hungry and tired, they introduced breaks in the following session plan after discussing the problem; acknowledging that they have learned that a new unfamiliar activity requires more time than familiar ones; administrating homework and meeting after school to compensate for time lags; consciously allocating session time for devising the suggested plan. (**d**) *Setting:* A preference for a collaborative work was found probably due to the challenging task. However, MA was evidenced when students flexibly shifted to individual work when time constraints cues were perceived. (**e**) *Homework were Assigned* initially, when no gaps were perceived, due to habits and norms. MA was evidenced when time gaps have been perceived and homework were expected to save time. In addition to developing MA students demonstrated several difficulties such as a deficient ability to identify missing domain and procedural knowledge in their own cognition, evidenced by the longer-than-anticipated time required for processing information and by the help-seeking segments that were introduced only later, while enacting the plan; difficulty in operationalizing perceived cues into actions that would improve performance; unsuccessful attempts to strike a balance between different dichotomous factors like, time constraints and activities to be carried out, deep narrow understanding and superficial broader understanding, individuals' needs and group needs, or between personal preferences and more efficient options. Such balance can only develop through diverse experiences of learning to navigate in complex learning environments and to negotiate among its components.

Conclusions and Implications

A deficient knowledge exists about planning and monitoring as expressing MA applied in a long-term inquiry. Evidence of MA are difficult to observe. The present instrument explicated such evidence and hence promoted understanding of these phenomena. Researchers' efforts should be continued and directed toward the development of refined instruments that may capture the application of different metacognitive components. The current findings demonstrate the possibility of providing students with opportunities recommended by many researchers of science education: namely, to experience an authentic self-regulated inquiry that will promote the development of students' MA and science. The findings suggest that in spite of the many difficulties involved, high-achieving students at this age can cope with the complexity of the environment, utilize its sources, and gain academically and personally from their experiences. However, such a project requires teachers' expertise, students' full autonomy, and length of time. To achieve better planning abilities, and to construct accurate and flexible knowledge representations of planning, students have to experience and train in learning environments that promote their ability to orchestrate diverse activities while performing complex, long-term tasks.

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