THE DEVELOPMENT OF COMPUTATIONAL THINKING IN THE CONTEXT OF SCIENCE AND ENGINEERING PRACTICES: A SELF-REGULATED LEARNING APPROACH

Erin E. Peters-Burton[1], Timothy J. Cleary[2] and Anastasia Kitsantas[1]
[1]George Mason University, College of Education and Human Development, Fairfax, VA 22030, USA
[2]Rutgers, The State University of New Jersey
Graduate School of Applied and Professional Psychology, Piscataway, NJ 08854, USA

ABSTRACT

A quality educational experience for secondary students involves more than an acquisition of content knowledge; it entails providing students opportunities to develop a variety of thinking skills that enable integration of knowledge and the promotion of student self-directed learning outside of the classroom. One critical skill that is often underemphasized in education is computational thinking. The purpose of this conceptual paper is to discuss the parallels between the processes of computational thinking and self-regulated learning, and the corresponding implications of this integrated framework for instruction in secondary classrooms. Guiding our analysis is the premise that because computational thinking processes can be viewed as goal-directed processes, it is possible to use self-regulated learning theory as a framework for assessing and enhancing computational thinking. Secondary educators have minimal experience with teaching computational thinking in the United States, so not only is a clear definition of computational thinking necessary in the Next Generation Science Standards, it is also necessary to have a learning theory from which to structure this type of thinking.

KEYWORDS

Computational thinking; Computational practices; Self-regulated learning; Science and engineering practices

1. INTRODUCTION

Teaching content knowledge to secondary classrooms has been the focus of the educational system in the United States for many years, as seen in various national curriculum efforts (AAAS, 1993; NRC, 1996). However, a quality educational experience for secondary students involves more than an acquisition of content knowledge; it entails providing students opportunities to develop a variety of thinking skills that enable integration of knowledge and the promotion of student self-directed learning outside of the classroom. One avenue of thinking skills that is worthwhile to pursue is a literacy of the digital world because it allows the development of self-awareness of the symbolic nature of our world and the processes of one's own learning otherwise known as metacognition (Wheeler, 2012). Along this line, a key thinking skill that is underused in the United States is computational thinking (CT), which is broadly defined as a way of "solving problems, designing systems and understanding human behavior by drawing on the concepts fundamental to computer science" (Wing, 2006, p. 33). Since few U.S. educators have much experience with CT, it is important to not only clearly define this term but to also examine and conceptualize this type of thinking from the lens of learning theories. Further, because it is important for students to be able to initiate and guide their use of CT, we believe that self-regulated learning (SRL) theories provide an ideal framework from which to explore how students engage in the computational thinking process (English & Kitsantas, 2013; Zimmerman, 1990). The purpose of this conceptual paper is to discuss the parallels between the processes of CT and SRL, and the corresponding implications of this integrated framework for instruction in secondary classrooms. Guiding our analysis is the premise that because CT processes can be viewed as regulatory, goal-directed processes, it is possible to use SRL theory as a framework for assessing and enhancing CT.

2. OVERVIEW OF COMPUTATIONAL THINKING

There are three dimensions to computational thinking: computational concepts, computational practices, and computational perspectives. Computational concepts are the notions students use as they engage in design, such as iteration and parallelism; computational practices refers to the processes students develop as they engage with the concepts, such as debugging; and computational perspectives which includes the learners' formation of viewpoints about the world and themselves. For the purposes of this paper, we are interested in the component of computational practices because they represent goal-directed behaviors and skills that comprise processes key to computational thinking. Such skills, defined in Table 1 (Grover & Pea, 2013), include the consideration of the benefits and limitations of the resources in an environment, reformulation of a difficult problem into one we can solve, and recursive thinking about correctness, efficiency, and aesthetics (Wing, 2006).

Table 1. Computational Practices and Description

Computational practices	Description
Abstractions and pattern generalizations	Examining a group of patterns and describing them in a way that is clear and efficient
Systematic processing of information	Using heuristics to make sense of an event
Symbol systems and representations	Portraying an often abstract event with a simplified concrete object
Algorithmic notions of flow control	Managing data using a specified procedure
Structured problem decomposition	Breaking down a complex problem or system into parts that are easier to understand
Iterative, recursive, and parallel thinking	Repeating thinking in cycles to meet a goal (iterative), think about your thinking (recursive), and ability to focus thinking in specific directions (parallel)
Conditional logic	Asserting that the occurrence of one event depends on the occurrence of another
Efficiency and performance constraints	Considering hindering and beneficial factors involved in a process
Debugging and systematic error detection	Engaging in a methodical process for finding and reducing defects

Because novices are often unaware of the many tactics embedded in computational practices (CPs) and will also struggle to use the strategies that they learn in class to solve problems, a framework is needed to delineate the *process* through which students engage in CT as well as their skill in managing the quality of this type of thinking. Much like any complex problem-solving activity, CT entails an integration of processes such as abstraction, decomposition, separation of concerns, problem solving, using randomization, designing systems, transforming, and simulating solutions. For novices, using these processes in an integrative fashion can be quite overwhelming. Therefore, we advocate conceptualizing CT as a series of goal-directed regulatory processes because it guide instruction and help students become more strategic and self-directed in their explorations using CT. Further, we believe that teachers can help students become "regulated" computational thinkers by providing feedback to students about the processes they use when engaging in this process.

2.1 Self-Regulated Learning Theory

Self-regulated learning (SRL) is viewed by many theorists as a goal-directed process whereby a person identifies a problem, examines relevant data to inform or develop and solution plan, implements this strategic plan, and then evaluates the effectiveness of this plan in achieving one's goal. From our perspective, CPs parallels the regulatory process because it involves making a series of judgements toward a solution to a problem, deploying tactics to iteratively conceptualize problems, identifying patterns in data such as points of divergence and convergence, and troubleshooting problems during the process. Also similar to SRL, to be able to engage in the iterative processes of CT, students must be motivated to do so, possess knowledge of tactics to reach their goals, and be able to effectively monitor and evaluate how well they are proceeding to a problem solution.

Self-regulatory methods of learning have been shown to be effective in aiding learners to explicitly analyze the skills or knowledge that is needed to achieve a particular goal in areas such as academic studying (Cleary & Zimmerman, 2004; Thomas & Rohwer, 1986), use of instructional media (Henderson, 1986), metacognitive engagement (Corno & Mandinach, 1983), athletics (Kitsantas, Zimmerman, & Cleary, 2000), writing revision (Zimmerman & Kitsantas, 2002), and scientific epistemologies (Peters & Kitsantas, 2010). Using the iterative self-regulation model as a lens for CT, the indistinct task of teaching and learning CPs can be made more concrete.

Zimmerman (2000) captured this process in terms of a cyclical feedback loop consisting of three phases: forethought, performance, and self-reflection (see Figure 1). Although this figure highlights abstraction and pattern generalization, any of the CPs could be applicable. The forethought phase refers to influential processes, such as analyzing tasks and setting process-oriented goals, that precede efforts to act and set the stage for action. The performance phase includes processes that occur during learning, such as implementation of task strategies and metacognitive-monitoring. The self-reflection phase refers to the processes that occur after learning or performance, such as the use of standards to make self-judgments about the performance, that collectively influence how a person responds to their performance. Because students continuously cycle through the feedback loop during learning, when students enter successive iterations of the loop, they are better positioned to use forethought, performance, and self-reflection processes in future learning.

2.2 Self-Regulated Learning: Creating Learning Environments that Foster Computational Thinking in the Classroom

Although self-regulatory processes are internally driven, they can be guided and facilitated by mentors and appropriately- constructed learning environments (Zimmerman, 2000), thus allowing a teacher to serve as a model to teach how CT is performed in a directed way. Since CT can be seen as a skill set for students to be competent in a problem-solving process, SRL can be a helpful framework to help students develop and use the tactics they need to employ to think computationally. By using a SRL framework, teachers can help students to organize information and skills, formulate solutions to a defined problem, and reflect on their problem-solving to create a more optimal process in the next iteration of problem solving. SRL is a way to manage the conceptual thinking process; an algorithm which analyzes thinking processes for the most effective path from problem identification to solution generation.

Teachers can help students become "regulated" computational thinkers by helping them to self-monitor their use and application of CT skills and by also providing them with additional feedback regarding the processes they use and need to refine when engaging in CT. Measures of SRL, such as SRL microanalysis (Cleary, 2011), can be used as both an instructional prompt and as an assessment tool of student progress. Unlike traditional questionnaires or rating scales, this structured interview assessment protocol is considered a type of event measure of SRL because it examines students' regulatory processes (goal-setting, planning) as students engage in specific learning tasks or activities. Because this type of assessment generates qualitative and quantitative, process-oriented information about *how* students engage in a task, teachers can use this approach and the corresponding data it yields to generate "actionable feedback" for students. Thus, although we know what CT *is*, we do not yet fully understand *how* to employ CT or how to help teachers better understand how their students engage in CT. Given that SRL microanalytic questions reveal information about how students set goals metacognitively monitor their progress, evaluate their performance, and adapt their CT, this approach can be extremely useful in obtaining information about students' SRL processes while engaged in CPs and in providing information about students' quality of execution of CPs for teacher assessment of student growth.

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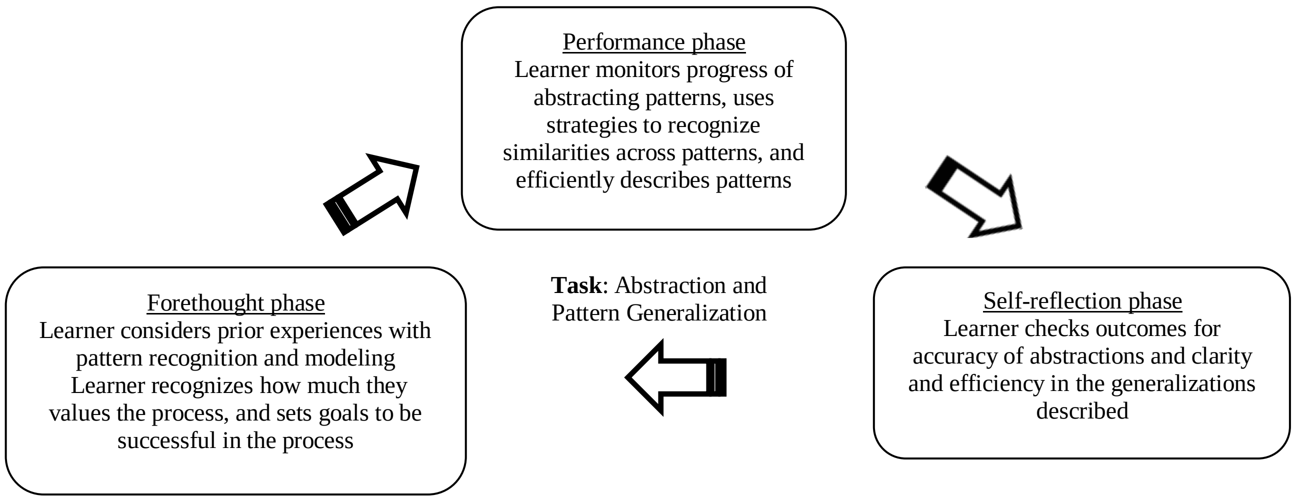

Figure 1. Self-regulated learning in abstraction and pattern generalization (adapted from Zimmerman, 2000)

2.3 Teaching Computational Thinking in the Context of Science and Engineering Practices

The minimal emphasis on CT in secondary curriculum in the U.S. is most readily observed in the most recent national standards in the U.S., the *Next Generation Science Standards (NGSS)*. The *NGSS* weaves together three strands of learning domains: Disciplinary Core Ideas, Cross Cutting Concepts, and Science and Engineering Practices. Disciplinary Core Ideas set the factual content standards that are the building blocks of the curriculum. The Science and Engineering Practices explain the disciplinary process skills that embody the development of science content knowledge, and the Cross Cutting Concepts represent broad themes that help to categorize the other standards into ideas that are essential to science. In this format, the Science and Engineering Practices are central to being able to learn about how content ideas are generated in the discipline of science. As one of the eight practices, *NGSS* defines “Using Mathematics and Computational Thinking” as using mathematics to accomplish investigations, perform analyses, and build complex models (NRC Framework, 2012).

It is notable that NGSS is not aligned to the ways the field defines CT. In fact, it describes CT more in terms of using mathematics. Because these standards will guide all future curriculum development, it is alarming that there is very little resemblance to the ways that the research-base defines CT and the practice of CT as defined in the NGSS. More efforts will be needed to help educators understand the gaps in NGSS descriptions of CT relative to the descriptions used in the field of computer science. We believe that teaching CPs through an SRL framework is one way that CT can be strengthened in curriculum. Strategically approaching how students are engaged in the task requires knowing what key features of CT we want students to know, and CPs provide a tangible, goal-oriented process from which to instruct and assess student learning.

3. CONCLUSION

Not only is CT underused in the United States (Wing, 2006), CT representation in national standards is glossed over and misaligned with the research-based concept of CT. Building students CT is a powerful and necessary component of instruction because it represents a universally applicable skill set. Although CT provides important skills, it is not well-represented in curriculum offered the United States. Secondary educators have minimal experience with teaching CT, so not only is a clear definition of CT necessary in the standards, but a learning theory from which to structure this type of thinking is also of vast importance. SRL theory provides a compelling and integrative framework from which CT skills can be taught. Constructing a mental toolkit of strategies from various perspectives to solve problems and design systems results in people who are better thinkers and learners.

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