STUDENTS’ WAYS OF THINKING IN A COMPUTER-BASED MATHEMATICS INVESTIGATION PROJECTS

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This paper explores students’ ways of thinking in a computer-based mathematics investigation projects. The paper draws from a preliminary analysis of data collected from first year of study that seeks to examine how post-secondary mathematics students learn to use programming as a computational thinking instrument for mathematics. Two distinct thinking styles that emerged during data analysis of two participants are discussed.

INTRODUCTION

The reality that STEM competencies fluid the engine of today’s knowledge-based economy is a well-established view. Subsequently, research in this area is dynamic and explores a myriad of interwoven factors that are deemed to hold together the fabric of STEM education. Turkle and Papert (1992) explore the issue of equity in the field of computer under the theme of epistemological pluralism, purporting that equity at even the most rudimentary level of computation necessitates “accepting the validity of multiple ways of knowing and learning (p.22).

Turkle and Papert (1992) argue that while the computer is socially constructed as the hallowed hall where the privileged thinking of abstraction, formalism, and logic meet, the assumption is vastly inaccurate. They contend that, contrary to this belief, the computer supports multiple ways of knowing and thinking. This is not only a strong argument for equity in STEM field but also a powerful line of reasoning for assessing student thinking in mathematics and programming. The computer provides researchers with the avenue to assess situated knowledge since it “forces general questions about intellectual style to reveal an everyday face” (Turkle & Papert, 1992; p 22); it allows the abstract to be dissected to see personal appropriations, strategies, schemes, and concepts-in-action. Informed by Turkle’s and Papert’s (1992) research, this paper focuses on analysis of two students, Jim and Ashley (pseudonyms), contrasting ways of thinking as they learn to appropriate programming as an instrument for mathematics investigations.

The paper draws from year one of a five-year study entitled “Educating for the 21st Century: Post-graduate Students Learning Progmatics (Computer Programming for Mathematical Investigation, Simulation, and Real-world Modeling). The study addresses the need to empower students within the STEM field and to better understand the complexities involved when students learn to appropriate tools such as ‘progmatics’. The study focuses on the question of how students come to appropriate programming as a computational thinking instrument for mathematics in the context of three ‘progmatics’-focused undergraduate mathematics courses at Brock University, called Mathematics Integrated with Computers and Applications (MICA). This course sequence teaches students the fundamentals of programming for conducting mathematical explorations and applications.

The context of this study is not only suitable to analyzing cognitive processes due to the computer's ability to engage multiple ways of thinking; but it is also suitable since it gives access to conceptual fields. Vergnaud (2009) posits that conceptual fields consist of a collection of contrasting situations and concepts that should be analyzed to gain deeper insight into students thinking. Furthermore, Vergnaud (2009) purports that by conceptual fields the adaptive nature of knowledge can be explored; thus, researchers can observe the forms of structures of activity, the schemes, and how they are adapted to situations. In this paper, Jim's and Ashley's ways of thinking are presented as they adapt to situations within the 'progmatics' learning environment. Noteworthily, Vergnaud (2009) recommends, the test of cognitive activity in novel situations is important to analyze the development of mathematics competencies.

CONCEPTUAL FRAMEWORK

Our views of how students appropriate computational thinking as an instrument for mathematics investigation in 'progmatics' environments rely on Rabardel's and Bourmaud's (2003) instrumental genesis theory and Vergnaud's (2009) concept of operational knowledge.

Grounded in the constructivist epistemologies which emphasizes the sociocultural environment in human activities (Vygotsky, 1978), the instrumental genesis theory describes the construction process whereby an artefact is transformed into an instrument. Instrumental genesis involves two processes: instrumentalization and instrumentation. The instrumentalization process charts how the subject adapts himself to the tool: the appropriation of the artefact. This may include selection of appropriate functionalities, grouping, developing of function, modification of function, etc. The instrumentation process is subject-oriented and involves the subject's utilization schemes, affected by artefact, to accomplish a task (Rabardel & Bourmaud, 2003). In the instrumental genesis process, operational knowledge is required to develop schemes (Vergnaud's, 2009). Operational knowledge allows individuals to describe and give justification for actions that have been done or to be carried out.

In this, paper we make use of this fact to describe students' ways of thinking; specifically, in terms of thinking styles (Turcke & Papert, 1992). Thinking style is defined as an individual's general pattern of utilizing mental abilities to manage or govern daily tasks. Thinking style shows how we may perceive, understand, and solve challenges and problems within our environment; it is the core of learning as it informs how we appropriate (Sternberg, 1997)). Importantly, Sternberg, (1997) recommends that discussions pertaining to thinking styles should only address their differences as they are not classified as good or bad. They do not reflect abilities but are the approaches of individuals based on cognitive processes in response to challenges or situations.

METHODOLOGY

The present paper draws from data gathered in year one of the larger study, where six participants in the MICA I course were recruited voluntarily. Data gathered included each participant's four 'progmatics' projects, including both their program (called exploratory objects (EOs)) and assignment report, and semi-structured individual interviews that were conducted as a follow up to each assignment. Data also included online post-laboratory session reflections, where after each of the ten weekly two-hour MICA lab sessions, participants recorded reflections on their learning during the lab as prompted by guiding questions. Finally, all participants completed an online questionnaire before beginning the MICA I course, followed by individual interviews where participants were asked to elaborate on their questionnaire responses. This paper focuses on data from two participants – Jim and Ashley (pseudonyms).

Analysis of the study's qualitative data followed Creswell's (2008) general principles of qualitative data analysis: preparing and organizing data, exploring data, and describing and developing themes from the data. To begin the analysis, codes were developed according to categories informed by the theoretical framework and related literature, with additional codes emerging during the analysis process. Themes were consolidated among the six participants' analyses, leading to the development of sixteen overall themes. In addition, there were unconsolidated themes that were unique to one or more participants. In this paper, we present our preliminary analysis focused on one of those unconsolidated themes concerning thinking styles that emerged from two participants.

FINDINGS AND DISCUSSION

Using excerpt from the interviews of Jim and Ashley, we present and discuss the two distinct thinking styles: system thinking and linear thinking.

Jim entered the MICA 1 excited and curious to experience mathematics within a programming environment. In his baseline interview, Jim describes mathematics as a meaning-making process, which requires individuals to make conceptual connections. Although a beginner in programming, Jim approached his EO projects systematically by assessing the scope of his projects and then breaking them down into smaller programing tasks. We describe his general cognitive approach as system thinking style. System thinking, can be described as the cognitive ability to focus on interconnections between parts of a system while simultaneously understanding how the parts unified to form a whole. When asked about his approach for EO1, Jim's response demonstrates this type of thinking:

> Jim (EO1): I basically tried to organize and sort out what needed to be programmed …It just required a set of system nested within each other so once I know that I had to figure out how to program each individual system. This one check for prime. This one is a loop that goes from number input…down to two that sort of thing…Once I realized how to do that, I just kind of start programming and basically would add in more levels of complexity as they became necessary?

Ashley's analysis revealed a different pattern of thinking. Ashley entered MICA with about a-half year university programming experience. Based on her baseline interview, she seemed comfortable with coding, and also, confident in her math skills. However, having viewed the computer as a tool for calculations and checking answers she was skeptical about doing mathematics in a computer-based environment. Nevertheless, she was reassured that her proven technique of doing mathematics by practicing solution methods of exercises done in class would take her through the course. Ashley mainly approached her EO projects in a similar fashion by modifying codes from previous labs but found at times that she is not able to modify them enough to fit her needs.

We identify Ashley's thinking style as linear. Linear thinking is analytical, discrete, mechanistic and formulaic; it is based on linear cause-effect relationships (Bratianu, & Vasilache, 2009). Ashley's seemed to demonstrate this formulaic, linear thinking style by modifying the code that was provided in class. This worked for her EO1 but she encountered a roadblock when she attempted the formulaic style for her EO2.

> Ashley (EO1): I got the code from like our class when we calculated hailstone sequences, and I modified it, and then I did again, cause I want to like show a comparison, so…yeah it wasn't really that hard because we already had the code for it.

> Ashley (EO2): I use code from previous labs cause most of the things we needed we have done in previous lab so that was easy to adapt. My code was not fully functional because I couldn't really separate the integer into smaller integers. I couldn't figure out how to do that. Other than that it should have been ok

Linear thinking is useful for tackling relatively invariant task but is inadequate when the task involve complexity (Sadler-Smith & Shefy, 2007). It seems that Ashley's thinking style does not involve looking at the whole, the parts, and how they interrelate. On the other hand, Jim maintained a system approach for EO2, considering the parts that he needed to build his whole program.

> Jim (EO2): I think basically I would program each process in steps either into a function or when it was ready into the final method. So, I would program say a function to find the five functions of a number and then I would program a function to find exponent in mod n… basically make all the building blocks and then just fit them all. And then when they were all there I would just kind of put them all together. Kind of a simple method

CONCLUDING REMARKS

There is an awareness in research of the potential of a computer in affording multiple ways of thinking. In this paper, we offered a preliminary description of two distinct students' thinking styles as they learn how to use programming for mathematics investigations. Further data analysis from other participants is needed to see if there are other thinking styles.

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References

Bratianu, C., & Vasilache, S. (2009). Evaluating linear-nonlinear thinking style for knowledge management education. *Management & Marketing*, 4(3).

Rabardel, P., & Bourmaud, G. (2003). From computer to instrument system: a developmental perspective. *Interacting with Computers*, 15(5), 665.

Sadler-Smith, E., & Shefy, E. (2007). Developing intuitive awareness in management education. Academy of *Management Learning & Education*, 6, 186–205.

Sternberg, R. J. (1997). Thinking styles. New York: Campridge University Pres.

Turkle, S., & Papert, S. (1992). Epistemological pluralism and the revaluation of the concrete. *Journal of Mathematical Behavior*, 11(1), 3-33.

Vergnaud, G. (2009). The theory of conceptual fields. Human development, 52(2), 83.

Vygotsky, L. (1978). Interaction between learning and development. *Readings on the development of children*, *23*(3), 34-41.