Int J of Sci and Math Educ (2016) 14:243–248
DOI 10.1007/s10763-016-9727-9

Preface for the IJSME Special Issue: Metacognition for Science and Mathematics Learning in Technology-Infused Learning Environments

Ying-Shao Hsu[1] **· Paola Iannone**[2] **·**
Hsiao-Ching She[3] **· Allyson Hadwin**[4]

Published online: 3 March 2016

Introduction

Research on metacognition for learning and teaching has become a central issue in science and mathematics education (Zohar & Barzilai, 2013). Metacognition—composed of knowledge about cognition and control of cognition—plays a central role in contemporary models of constructivist-oriented and self-regulated learning (SRL). There are several definitions of metacognition proposed in the research literature. McComas (2014) defined metacognition as "the process of thinking about one's own thinking, or the act of monitoring and controlling one's thoughts and cognitive processes while learning and knowing what strategies are personally useful to carry out any task more effectively" (p. 63); others have defined metacognition in more everyday terms, such as "thinking about your thinking/learning/actions to improve your thinking/learning/actions as you are thinking/learning/acting, which in turn will enhance the thinking/learning/actions" (Ford & Yore, 2012, p. 264). Clearly, each of these definitions links learning, quality thinking, monitoring, and regulation in a dynamic, real-time, complex process and suggests that metacognition is composed of two clusters: awareness (knowledge about) and executive control (real-time self-management) of learning. However, the operational definitions and uses of metacognition, self-regulation, and SRL that are currently available in the literature are somewhat fuzzy and confused. Such confusion is partially due to the variety of views of learning (e.g., *cold*

✉ Ying-Shao Hsu
huannlin@mail.nsysu.edu.tw

[1] National Taiwan Normal University, Taipei, Taiwan

[2] University of East Anglia, Norwich, UK

[3] National Chiao Tung University, Hsinchu, Taiwan

[4] University of Victoria, Victoria, Canada

and *hot* varieties of behaviorism, cognitive development, conceptual change, constructivism, and cognitive science and neuroscience interpretations) held by educational researchers (Zohar & Dori, 2012). Dinsmore, Alexander, and Loughlin (2008) suggested that researchers have neglected the clarity of these concepts and their associated views of learning, have employed instruments without appropriate theoretical roots, and have not reflected adequately on the methodological limitations of such instruments.

Exploring the shared core meaning of the definitions of these fundamental constructs is necessary for reducing this troubling ambiguity. Even though metacognition and SRL share a common core that involves self-awareness and regulatory actions (Hsu, Yen, Chang, Wang, & Chen, 2014; Kaplan, 2008), they are qualitatively different constructs. Kaplan (2008) suggested that metacognition, self-regulation, and SRL are subtypes of self-regulated actions and proposed a multidimensional conceptual framework of self-regulated actions to facilitate awareness of the complexity of self-regulation. That framework includes three dimensions: self-aspects (the "subject" who is doing the regulating), objects of regulation, and strategies for engagement in the task (Fox & Riconscente, 2008; Kaplan, 2008). This multidimensional conceptual space allows researchers to define self-regulation as a set of characteristics with well-defined theoretical and practical meanings involving the person, the domain, and the approach. It includes *hot* affective and *cold* cognitive psychological features of the learner; general epistemic, ontological, and nature of the domain requirements and specific task features of learning/problem focus; and strategic procedural and process features of the problem-solving, inquiry, design, and science and engineering practices used to address the learning focus. This multidimensional conceptual framework of self-regulation, therefore, allows the investigation of such constructs in specific disciplines such as mathematics and science and their unique epistemic, ontological, and conceptual demands.

Recent literature (Ford & Yore, 2012; Winnie & Perry, 2000) on metacognition identifies concerns regarding (a) whether this construct applies to general learning events or to task-specific events, (b) the apparent gap between metacognitive awareness of cognition events or to task-specific events, (b) the apparent gap between metacognitive awareness of cognition and real-time control of cognition/self-management, (c) difficulties in measuring metacognitive awareness and self-management, and (d) the role of metacognition and other *cold* and *hot* factors in SRL. The intentions behind this special issue of the *International Journal of Science and Mathematics Education* were to document research on technology-infused environments as a potential solution to some of the issues raised above and, in particular, to address the lack of studies in self-regulation and metacognition in science and mathematics education.

Overview

This 2016 special issue starts by addressing some of the concerns raised above via a synthesis of recent research on metacognition in science education. Tang, Wang, Chang, Chen, Lo, and Tsai (2016) identify highly co-cited papers (i.e., pairs of articles cited in another article) to reveal the intellectual structure of metacognitive scaffolding. The profile of these highly co-cited papers is visualized through social network analysis; the two most cross-referenced underpinnings in the network are the studies about adaptive scaffolding for SRL and conceptual understanding and about younger students' metacognition in online inquiry environments. These studies indicate the effects of implicit versus explicit heuristic supports in facilitating discovery learning, the domain-general versus domain-specific scaffolds on conceptual understanding or problem solving, and the role of peer collaboration. Using exploratory factor analysis, the authors also identify emerging trends as non-technological metacognitive scaffolding and learners' behavior patterns and task analysis.

The two articles that follow address the potential of technology-infused learning environments to scaffold metacognition. Recently, more and more research in science and mathematics education is creating technology-infused environments to scaffold learners' cognition and supplement their metacognition in a classroom setting or in an e-learning setting that place more self-regulation demands on learners (Manlove, Lazonder, & de Jong, 2007). Therefore, it is worthwhile to consider technology-infused environments as both a critical problem space and a potential solution to address the role of self-regulation and metacognition in science and mathematics.

Chen and Chiu (2016) focus on the effects that collaboration scripts based on the Think-Pair-Share method had on metacognitive self-regulation and mathematical literacy after experiencing a multi-touch, design-based learning activity. The authors employed a quasi-experimental design to document the effects on four grade 5 classes where two classes were assigned to the collaboration scripts approach and two classes to the non-collaboration scripts approach. At the end of the activity, all students completed a metacognitive self-regulation questionnaire and a test to measure their mathematics literacy achievement. Analysis of the posttest data revealed that students using the collaboration scripts differed significantly from those without the scripts on overall metacognitive self-regulation and achieved better learning outcomes on higher-level items. This study—although it presents promising results regarding the use of collaborative scripts in a technology-infused learning environment—shows how complex the phenomena under study is and how difficult it is to obtain generalizable findings.

Chen, Huang, and Chou (2016) applied the COPES model (Winne & Hadwin, 1998) to design metacognitive scaffolding for Grades 11 and 12 students' experimental goal setting and planning of physics laboratory activities. This two-group (treatment and comparison) study explored the type and placement of goal setting and planning scaffoldings in an inquiry-oriented microcomputer-based laboratory (MBL) on the low achievers' inquiry performance, conceptual understanding, attitude toward science, self-efficacy, and gender differences. Inquiry worksheets and MBL were provided for students during a self-contained investigation on Boyle's Law. Their results indicate that the male students in the treatment group gained significantly more conceptual knowledge than the female students, suggesting the male students benefited more regarding goal setting and planning. Although the female students set more and higher goals for their overall learning, the male students seemed to be more aware of their learning on a micro-scale.

The last two articles in this special issue aim to present specific examples of how science and mathematics educators (a) examine the effects of cognitive and metacognitive supports on science or mathematics achievement and self-regulation and (b) apply methodologies for metacognition and SRL research in the context of innovative pedagogies. Important aspects in the metacognition literature are measuring metacognitive awareness and self-management, clarity of cognitive and metacognitive scaffolding, and factors influencing development of metacognition connected to the evolution of the ways in which researchers perceive learning to happen. Models in mathematics and science education frequently evolve. Often one existing model is modified to incorporate new empirical evidence and emerging theories rather than undergoing radical changes, resulting in drastically unrecognizable representations of the original model. Similarly, views about science and mathematics learning have evolved over the last 50 years; new ideas believed to be embedded in and critical to human learning have been introduced. These new ideas often run parallel to the use of pre-existing ones, despite the fact that they can have drastically different underlying assumptions and theoretical foundations. A classic example of the continuation across new views of learning is objective test items. The use of objective test items was first justified by the behaviorist interpretation of learning, which suggested that complex knowledge and learning could be deconstructed into logical sequences of simple knowledge; thereby, complex understanding could be asserted and documented with a collection of simpler constructs. Other discrepancies were caused by the generation of similar or conjoined constructs from different foundations—philosophy, psychology, progressive education, and so on (Ford & Yore, 2012).

Alpaslan, Yalvac, Loving, and Willson (2016) explore the relations among students' personal epistemologies, achievement goals, learning strategies, and achievement using structural equation modeling (SEM). They documented the epistemic beliefs (justification, certainty, source, and development of knowledge), SRL (extrinsic motivation, intrinsic motivation; rehearsal, elaboration, and organization strategies; critical thinking, metacognitive self-regulation), and achievement in physics (course grades). The SEM results showed that 209 Turkish high school (Grades 9–11) students' personal epistemology influenced their motivation and metacognitive strategies.

van Velzen (2016) explored an under-researched area of metacognition and mathematics education with an investigation of Grade 11 mathematics students' metacognitive knowledge about problem solving and their problem-solving performance. Eighteen students in a mathematics and science stream of a Dutch urban school were given three two-part thought-provoking tasks to solve and then were asked open-ended questions to provide a reflective account of their knowledge about problem solving (4 questions) and problem-solving processes and strategies (5 questions). Established analysis and coding of the responses revealed four levels of explicitness and five levels of systematicity that correlated highly with problem-solving performance. This preliminary study reveals the potential of much-needed research in metacognitive knowledge, metacognitive self-management, and mathematics learning through problem solving.

Closing Comments

The articles in this special issue reveal how cognitive and metacognitive scaffolding influences learners' science and mathematics achievement and self-regulation in technology-infused learning environments for a range of participants, pedagogies, and outcomes. They illustrate the need for metacognitive knowledge and problem solving of ill-structured and thought-provoking tasks. The articles cover a range of participants from elementary and middle school students to senior high school students.

The target learning performances considered in this special issue include inquiry, problem solving, conceptual understanding, and graphing while integrated metacognition was into instructional designs or assessments. The authors use a variety of theoretical perspectives. For example, Chen et al. (2016) adopt specific models related to inquiry learning and, together with Chen and Chiu (2016), address the potential of technology-infused learning environments to scaffold metacognition. Alpaslan et al. (2016) survey the relation between high school students' personal epistemology, motivation, and metacognitive strategies, while van Velzen (2016) explores more fundamental questions within and relationships between metacognitive knowledge (awareness) and mathematics problem solving. It is evident from the articles in this special issue that the research on the practical meaning of metacognition and self-regulated learning based on different SRL models, scaffolding designs for SRL, and methodological issues for measuring metacognition represents a major trend and future focus for studies about metacognition for learning and teaching. However, there are still contested definitions and applications of metacognitive knowledge about (awareness) and metacognitive self-management of specific learning tasks, disciplinary practices, and processes. Further research is needed to clarify these definitions and the potential of their application to students' learning.

Acknowledgments We would like to thank Professor Huann-shyang Lin, Editor of *International Journal of Science and Mathematics Education*, for the opportunity to serve as Guest Editors for this special issue and acknowledge the reviewers who provided invaluable comments and feedback to the authors. The Guest Editors are especially grateful to the insightful suggestions provided by Professor Larry D. Yore and to the editorial suggestions provided by Sharyl A. Yore.

References

Alpaslan, M. M., Yalvac, B., Loving, C. C. & Willson, V. (2016). Exploring the relationship between high school students' physics-related personal epistemologies and self-regulated learning in Turkey. *International Journal of Science and Mathematics Education*. Advance online publication. doi:10.1007/s10763-015-9685-7.

Chen, C.-H. & Chiu, C.-H. (2016). Collaboration scripts for enhancing metacognitive self-regulation and mathematics literacy. *International Journal of Science and Mathematics Education*. Advance online publication. doi:10.1007/s10763-015-9681-y.

Chen, S., Huang, C.-C. & Chou, T.-L. (2016). The effect of metacognitive scaffolds on low achievers' laboratory learning. *International Journal of Science and Mathematics Education*. Advance online publication. doi:10.1007/s10763-015-9691-9.

Dinsmore, D. L., Alexander, P. A. & Loughlin, S. M. (2008). Focusing the conceptual lens on metacognition, self-regulation, and self-regulated learning. *Educational Psychology Review, 20*(4), 391–409. doi:10.1007/s10648-008-9083-6.

Ford, C. L. & Yore, L. D. (2012). Toward convergence of critical thinking, metacognition, and reflection: Illustrations from natural and social sciences, teacher education, and classroom practice. In A. Zohar & Y. J. Dori (Eds.), *Metacognition in science education: Trends in current research* (Vol. 40, pp. 251–271). Dordrecht, The Netherlands: Springer. doi:10.1007/978-94-007-2132-6_11.

Fox, E. & Riconscente, M. (2008). Metacognition and self-regulation in James, Piaget, and Vygotsky. *Educational Psychology Review, 20*(4), 373–389. doi:10.1007/s10648-008-9079-2.

Hsu, Y.-S., Yen, M.-H., Chang, W.-H., Wang, C.-Y. & Chen, S. (2014). Content analysis of 1998–2012 empirical studies in science reading using a self-regulated learning lens. *International Journal of Science and Mathematics Education*. Advance online publication. doi:10.1007/s10763-014-9574-5.

Kaplan, A. (2008). Clarifying metacognition, self-regulation, and self-regulated learning: what's the purpose? *Educational Psychology Review, 20*(4), 477–484. doi:10.1007/s10648-008-9087-2.

Manlove, S., Lazonder, A. W. & de Jong, T. (2007). Software scaffolds to promote regulation during scientific inquiry learning. *Metacognition and Learning, 2*(2), 141–155. doi:10.1007/s11409-007-9012-y.

McComas, W. F. (2014). Metacognition. In W. F. McComas (Ed.), *The language of science education: An expanded glossary of key terms and concepts in science teaching and learning* (p. 63). Rotterdam, The Netherlands: Sense.

Tang, K.-Y., Wang, C.-Y., Chang, H.-Y., Chen, S., Lo, H.-C. & Tsai, C.-C. (2016). The intellectual structure of metacognitive scaffolding in science education: a co-citation network analysis. *International Journal of Science and Mathematics Education*. Advance online publication. doi:10.1007/s10763-015-9696-4.

van Velzen, J. H. (2016). Eleventh-grade high school students' accounts of mathematical metacognitive knowledge: explicitness and systematicity. *International Journal of Science and Mathematics Education*. Advance online publication. doi:10.1007/s10763-015-9689-3.

Winne, P. H. & Hadwin, A. F. (1998). Studying as self-regulated learning. In D. J. Hacker, J. Dunlosky & A. C. Graesser (Eds.), *Metacognition in educational theory and practice* (pp. 277–304). Mahwah, NJ: Lawrence Erlbaum.

Winne, P. H. & Perry, N. E. (2000). Measuring self-regulated learning. In M. Boekaerts, P. R. Pintrich & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 531–568). San Diego, CA: Academic.

Zohar, A. & Barzilai, S. (2013). A review of research on metacognition in science education: current and future directions. *Studies in Science Education, 49*(2), 121–169. doi:10.1080/03057267.2013.847261.

Zohar, A. & Dori, Y. J. (2012). *Metacognition in science education: Trends in current research*. Dordrecht, The Netherlands: Springer. doi:10.1007/978-94-007-2132-6.