Title	Designing learning contexts using student-generated ideas
Authors	Rachel Lam, Lung-Hsiang Wong, Matthew Gaydos, Jun Song Huang, Lay Hoon Seah, Michael Tan, Manu Kapur, Katerine Bielaczyc and William Sandoval
Source	*12th International Conference of the Learning Sciences (ICLS 2016), Singapore, 20-24 June 2016*
Published by	International Society of the Learning Sciences

Original citation: Lam, R., Wong, L. -H., Gaydos, M., Huang, J. S., Seah, L. H., Tan, M., … Sandoval, W. (2016). Designing learning contexts using student-generated ideas. In C. –K. Looi, J. Polman, U. Cress & & P. Reimann (Eds.), *Transforming learning, empowering learners: The International Conference of the Learning Sciences (ICLS) 2016, Volume 2* (pp. 1090-1097). Singapore: International Society of the Learning Sciences.

Designing Learning Contexts Using Student-Generated Ideas

Rachel Lam (co-chair), Lung-Hsiang Wong (co-chair), Matthew Gaydos, Jun Song Huang, Lay Hoon Seah, Michael Tan
rachel.lam@nie.edu.sg, lunghsiang.wong@nie.edu.sg, matthew.gaydos@nie.edu.sg, david.huang@nie.edu.sg, layhoon.seah@nie.edu.sg, michael.tan@nie.edu.sg
National Institute of Education, Nanyang Technological University, Singapore

Manu Kapur, The Hong Kong Institute of Education, mkapur@ied.edu.hk

Katerine Bielaczyc (discussant), Clark University, kbielaczyc@clarku.edu
William Sandoval (discussant), University of California Los Angeles, sandoval@gseis.ucla.edu

Abstract: This symposium proposes a genre of learning designs called Student-Generated Ideas (SGIs), based on designing learning contexts that promote students as critical producers, distributors, and consumers of knowledge. SGIs place students' ideas at the center of learning designs, considering the learning process as well as the learning goals/outcomes. By soliciting and foregrounding students' diversified ideas in the classroom and beyond, the learning environment communicates to students that their ideas matter to others and that they have a position of responsibility to their own and their peers' learning processes. The notion of SGIs is embodied in a repertoire of studies at the Learning Sciences Lab, National Institute of Education, Singapore, that offer varied yet overlapping interpretations of how student ideas can inform the design of learning contexts. In sharing the core design principles for SGIs approaches, this work contributes important components to the learning sciences discipline and changing educational practice.

Keywords: Student-Generated Ideas (SGIs), Productive Failure, preparation for collaboration, language demands of science, learning in makerspaces, game-based learning, seamless learning

Introduction

Student-Generated Ideas (SGIs) embody principles for the design of learning environments that promote students as critical producers, distributors, and consumers of knowledge. Rather than focus on mastery of expert knowledge, a major goal of 20th century education, SGIs leverage students' ideas as the basis for designing educational settings. Putting students' ideas at the center of the classroom communicates to students that their ideas matter to others and that they have a position of responsibility to contribute to knowledge advancement in the classroom community. Highlighting the inquiry process of the student intends to support students to take control of their learning processes. In this way, students not only learn the target subject(s), but also come to understand the means for working with and creating knowledge (e.g., finding problems, re-representing or re-modeling knowledge, locating resources, testing ideas through experimentation, developing skills in argumentation and the critique of various perspectives, etc.). The burden of SGIs research is to design a smart context rather than to assess a student as a "smart" or "not a smart" individual (Barab & Plucker, 2006). Through such designs, student "ability" becomes a function of context, expectations, and tasks. These designs promote engagement and are founded on learning potential, rather than formally measured achievement.

Our proposed symposium on the SGIs approach is built on a strong foundation of studies at the Learning Sciences Lab, National Institute of Education, Singapore, that create classroom innovations for 21st century learning. These studies have been carried out using a variety of contexts (formal and informal), domains (mathematics, science, language, etc.), tools (computer-mediated communication, mobile technology, game designs, etc.), and schools, and thus, present an opportunity for building invariant meta-design principles across the variant particulars of our projects. The design and enactment of SGIs research necessitates intensive collaboration with classroom teachers, not always but typically, through design-based research or design experiments. Such close collaboration helps teachers to rise above being mere experts of content who pass along their expertise to students; they also develop the capabilities to become designers of smart contexts, centering learning activities on students' generated problems, representations, language, learning strategies, and/or solutions. In addition, close collaboration with teachers through authentic, experiential approaches sustained over a period of time has the added advantage of shifting both the teachers' and students' perceptions of learning towards a student-centric educational culture. Thus, our work aims to enhance both theory and practice.

This symposium will be conducted in an interactive format. It will begin with a quick "firehose" session where a presenter of each set of studies/projects shares her/his work in three minutes. Next will be a combined poster/roundtable session where presenters engage in discussions with audience members at their respective stations. Audience members may visit any stations of interest. Moreover, in light of the spirit of SGIs, participants will be offered the opportunity to note their own questions, interpretations, critiques, or ideas on either the general notion of SGIs or on any of the individual studies/projects. During the last segment of the symposium, our two discussants will lead a critical discussion of the presentations, interactions, and audience contributions, and synthesize the salient theoretical and practical crosscutting issues.

Preparation for learning from collaboration by generating ideas

Rachel Lam

It is well understood that simply placing a small group of students together in a classroom does not guarantee effective collaborative learning (Barron, 2003; Dillenbourg, 2002). To encourage students to capitalize on the affordances of collaborating to learn, researchers have examined various instructional interventions such as: teaching students collaboration skills so that students collaborate better (Asterhan & Schwarz, 2009; Rummel, Spada, & Hauser, 2009), scaffolding interactional moves via prompts or scripts to facilitate effective collaboration (Fischer, Kollar, Stegmann, & Wecker, 2013; Walker, Rummel, & Koedinger, 2011), or designing tasks to elicit substantive discussions during collaboration (Engle & Conant, 2002; Kapur & Bielaczyc, 2012). It is apparent that students need support to collaborate effectively for learning, but the best ways to do that remains an open question.

To help students make the most of collaborative learning experiences, we take the approach of designing instructional tasks in ways that invoke effective collaborative mechanisms without directly imposing on student behaviors and interactions. Our task design utilizes a preparation for learning framework, whereby carefully designed preparatory activities promote the cognitive and affective *readiness* to learn from subsequent collaboration. The tasks are grounded in eliciting students' naïve representations relative to the content-to-be-learned by having students freely generate ideas first individually, and then afterward discuss ideas in a small peer group. Our experimental studies conducted *in situ* have shown that compared to learning the canonical representations explicitly and applying them in a problem task, freely generating ideas leads to significant learning gains after collaborating, particularly on transfer items. In addition, the examination of student artifacts produced throughout the learning activity has shown that learning can be attributed specifically to collaborating, only in conditions where students freely generated ideas during preparation. Furthermore, by examining students' discussions, we posit that generating ideas before formally learning concepts invokes preparatory mechanisms to a greater extent, which consequently increases the extent to which collaborative mechanisms are invoked.

During this symposium, I will share our current work on this learning design, which we call Preparation for Future Collaboration (PFC). The design draws from the Preparation for Future Learning paradigm (D. Schwartz), Productive Failure (M. Kapur), and the Interactive-Constructive-Active-Passive ICAP framework (M. Chi). We have been partnering with teachers in Singapore to co-design PFC learning tasks for low-achieving students from the upper primary to secondary levels in various subject areas (environmental sustainability, urban planning, language, mathematics), empirically test our designs in classrooms, and record and analyze student discussions during collaboration. I will offer insights on working with teachers in the Singaporean context, a highly test-driven educational culture within a strong top-down hierarchical education system. To date, our work has been received by Singaporean educators as a "truly student-centered" kind of instruction, yet has also been met with apprehension as teachers shift from their familiar teacher-centric instructional approaches towards instruction based on student-generated ideas.

Investigating the learning and transfer effects of student-generated analogies

Jun Song Huang and Manu Kapur

This presentation expands the Productive Failure learning design (Kapur, 2008; Kapur & Bielaczyc, 2012) by investigating the effects of students generating analogies before receiving formal instruction. The design examines the learning and transfer mechanisms involved in different pedagogical sequences (i.e., generation first or instruction first) and in different forms of analogical thinking (i.e., generating analogies or generating analogical mappings between given analogies).

The design seeks to extend the investigation of the learning mechanisms involved in Productive Failure in two aspects. First, the Productive Failure learning design typically requires students to generate problem solutions during the generation phase. Such activity allows students to recognize their knowledge gaps and

subsequently attend to those gaps at the instruction phase (Kapur, 2014). By investigating generative activities that do not involve problem solving, this work addresses how to design for Productive Failure without orienting towards a problem goal state. Second, through problem solving, the Productive Failure learning design activates and differentiates students' relevant prior knowledge (Kapur, 2014). The patterns of prior knowledge activation and differentiation have been found to be linked to the effects of learning and transfer (Kapur 2014, 2015). Our design question is whether an activity that is targeted to activate and differentiate relevant prior knowledge by providing more degrees of freedom might be better for learning and transfer than an activity that has less degrees of freedom (i.e. is more constrained). To explicate, the activity that requires students to generate analogies (which is more aligned to the conventional Productive Failure generation phase) has more degrees of freedom compared to the activity that requires generating analogical mappings for given analogies. We speculate that student learning and transfer may be enhanced when they are given more degrees of freedom in generation, especially when they generate first before instruction, because this may better activate and differentiate relevant prior knowledge.

We conducted an experimental study to investigate the design. One hundred and twenty seventh-graders in a high-achieving girls' school in Singapore participated in the study. The curricular unit covered how to formulate a system of linear equations for mathematics word problems. Findings partially confirm our hypothesis, with indicators suggesting that generating analogies before formal instruction enacts different learning mechanisms. In this symposium we share our preliminary data analysis that helps to expand the understandings of the Productive Failure learning design.

Addressing the language demands of science using student-generated representations

Lay Hoon Seah

The fundamental role of language in science has been widely recognized over the past decades, encapsulated in notions such as fundamental literacy (Norris & Phillips, 2003), disciplinary literacy (Moje, 2007) and science literacy for all (Yore, 2012). Underlying these notions is the recognition that scientific language has its own specialized features, norms and conventions that distinguish it from language used in other disciplines and in everyday life (Gee, 2004). Research on students' use of language (e.g. Frändberg, Lincoln & Wallin, 2013; Schoultz, Säljö, & Wyndhamn, 2001; Seah, Clarke & Hart, 2015) has also highlighted students' difficulties in interpreting and employing the language of science. A critical aspect of science teaching thus involves attending to and addressing the demands inherent in the use of the language of science. However, while science teachers may recognize the language demands of science, they face challenges in designing lessons that foreground and address the language demands of science in an explicit way (Seah, 2015).

In this study, the researchers worked collaboratively with science teachers to design lessons that took into consideration the language (in addition to the conceptual) demands of science. As with the other studies in this symposium, SGIs was an important component of the lesson design, and in particular, its manifestation in the form of linguistic representations. These student-generated representations played a key role in the lessons in several ways. Firstly, they provided one of the means by which to determine the nature of the language demands and the extent to which these demands needed to be addressed in the lessons. This was achieved by examining the similarities and differences between the student-generated representations and the scientific language during the process of lesson planning and review. During the lessons, these representations became the target of intervention as well as a resource for teaching. For example, teachers highlighted the linguistic differences between the student-generated representations and the canonical use of scientific language to bring about awareness of the language demands of science.

Drawing on a variety of data such as teacher interviews, lesson videos and videos of the lesson planning sessions with teachers, I analyzed the process in which the student-generated representations were utilized across different contexts (before, during and after lessons). The analysis revealed the connections (or lack thereof) that the teachers made among the various roles of these representations, and through this I offer insights into the challenges teachers encountered and share some possible ways for supporting teachers to use student-generated representations effectively.

Makerspaces as sites for studying embodied creativity practices

Michael Tan

While research in cognition has moved into the realm of the sociocultural with the landmark work of distributed cognition researchers, in recent years some attention has returned to the individual as the unit of analysis.

Specifically, the embodied cognition research agenda has started to look at the role of bodily actions and interactions with objects (and to a lesser extent, other humans) in cognitive processing tasks. Essentially, embodied cognition now supposes that actions need to be considered as cognitive if they perform the role of an equivalent process "in the brain." Thought about this way, embodied cognition is a means of spreading the explanatory load for cognitive processes out of the skull, and to the body and beyond (Clark, 2001; Clark & Chalmers, 1998; Shapiro, 2011). This project is a means to explore the role of the body and its material interactions with reality when students learn through the generation of draft designs.

Using this embodied cognition perspective then, an interesting context to study is the phenomena of tinkering; loosely called "thinking with your hands" by design leaders, and widely acknowledged in makerspaces to herald a new way of learning STEM knowledge, skills, and dispositions. Yet, the question remains how to explain tinkering. Specifically, thinking about the phases of design problem solving, two major cognitive processes are ill-structured problem solving, and well-structured problem solving. Taking the geneplore (Finke, Ward, and Smith, 1992) model of creativity, the hypothesis remains that there ought to be two rather distinct roles that actions play in the design and making of artifacts (see, also, Goel, 2014). Given the widely advertised ability of makerspaces to facilitate innovativeness and creativity, I present my preliminary work studying the processes of tinkering in makerspaces.

Students in this study were presented a design prompt to create a device to attract teachers' attention, a collection of magnetically connectable electronics components, and some tools for cutting and joining materials. Six pairs of student volunteers were video-recorded in pull-out sessions of about an hour each, and the actions and talk during their design sessions were examined. Initial analysis indicates: (i) that students do not distinguish between distinct divergent generation and convergent problem solving phases, with more creative designers remaining open to suggestions for improvement throughout the entire design phase; (ii) student actions nonetheless demonstrate two distinct classes, with a higher degree of epistemic action associated with an exploratory phase of their activity even when they did not identify it as such. Implications for further research and practice will be discussed.

Designing for game design

Matthew Gaydos

Game design has been successfully used to introduce students to academic content and skills like programming (Kafai, 2006; Overmars, 2004) as well as so-called twenty first century curricula like digital literacy or design thinking (Games, 2008; Gaskin & Berente, 2011). However, aside from using it as a motivating activity (e.g. Cira et al., 2015), there are not well-tested approaches or frameworks for integrating game design into curricula (for games generally, see Foster & Shah, 2012). This is especially the case when using game design to teach content that is secondary to game production (e.g. biology as opposed to programming).

In this presentation, I describe a design-based research project in which an extensible geography card game is developed for use in Singapore classrooms. The card game is designed to provide students with a game-based model to think *with* as they engage the target content. Once students understand the game model, they may then be able to use it both for understanding other models and predicting outcomes of model perturbation, especially through their own designs (e.g. inventing new rules and cards).

Though these student-generated designs are theoretically useful, they may be impractical within Singapore classrooms, which tend to be oriented toward improving high-stakes assessment results (Chee, Mehrotra, & Ong, 2014; Hogan et al., 2013). Additionally, educational games bring with them a host of logistical challenges (Van Eck, 2006), and may be difficult to use with audiences unaccustomed to game-based approaches (Chee, Mehrotra, & Ong, 2014). The study that will be presented details the contextual factors that support and detract from student-generated game play and design as a pedagogical tool within a high-stakes test-centered system. Through interviews with teachers and students, it focuses on the perceived affordances and challenges of integrating games and game design into the curriculum.

Singapore's Ministry of Education has provided widespread support of game-based learning and other student-centered, technology-based pedagogical developments. Because of the centralized organization of Singapore's education system, there exist few mechanisms for feedback regarding how such policies influence practice or how successful enactments may be spread across sites. Teacher and student feedback is thus not only useful for understanding how these new pedagogical artifacts (including games) may be better developed and used, but provides a means for reflecting on the relationship between policy goals and classroom outcomes.

Seamless learning: Idea generation *from* and *for* cross-contextual learning processes

Lung-Hsiang Wong

Seamless learning is when a person experiences a continuity of learning, and consciously bridges the multifaceted learning efforts, across a combination of locations, times, technologies or social settings (Sharples et al., 2012; Wong, 2015). Despite often being characterized as "anytime, anywhere learning," the notion of seamless learning is however differing from e-learning. "Anytime, anywhere learning" could also refer to flow learning (Csikszentmihalyi, 1990; Sharples, 2015), i.e., to induce a flow state such that learners are so engaged in a learning activity that they lose awareness of their surroundings. Instead, seamless learning foregrounds the unique ecological constructs/resources in various learning spaces including artifacts, tools and people which/who could facilitate multifaceted tasks (Wong, 2015), e.g., the classroom for learning engagement and consolidations, physical spaces for situated and authentic learning, online platforms for information seeking/sharing and peer discussions, etc.

Thus, a holistic seamless learning experience requires learners not only to interact with other people (e.g., peer learners) and instructor-provided artifacts within a relatively closed learning environment (e.g., traditional classroom or e-learning portals), but also with the authentic environment and perhaps the Internet at large, where they may draw elements or information that they incidentally encounter or recall (e.g., building on prior knowledge or past experiences), exploit hidden affordances of *in situ* artifacts, and appropriate the right combination of these elements to "jointly mediate" (Wong, Chen & Jan, 2012) their *in situ* and/or cross-contextual learning tasks. Under such a perspective, learners may generate various forms of "ideas" throughout the learning process, encompassing not only the intermediate or final learner-created artifacts as representations of their current knowledge states, but also the process-related strategies that the learners figure out by themselves to improve their learning process or overcome novel learning problems. In light of this perspective, our team developed an alternative qualitative method known as "artifact-oriented analysis" (Wong, Chen & Jan, 2012), rooted in the Vygotskian notion of "mediation by artifacts" and distributed cognition to unpack the seamless learning process data collected through our studies (e.g., So, Seow & Looi, 2009; Wong, 2013). In a nutshell, as aspirations for lifelong learning, the advocates for seamless learning should entail the fostering of learners' dispositions and skills in self-generating "ideas" to advance their own learning endeavors.

Another important concept of seamless learning that is relevant to SGIs is "recontextualization." Earlier literature tended to dichotomize decontextualization and contextualization in expounding the differences between formal and informal learning (e.g., Hung, Lee & Lim., 2012; Lave & Wenger, 1991), perhaps due to privileging authenticity. We offer an alternative perspective of "recontextualization" (cf. Looi, et al., 2010) of skills, knowledge or meaning through the cross-contextual and cross-temporal learning trajectories. For example, an "idea" incubated in class may be practiced or reified in authentic settings, and later be scrutinized, enriched, transformed and/or challenged within the social learning spaces, with relevant but diversified personal perspectives, knowledge and experiences mediating the socio-constructivist discourse (e.g., Lewis, Pea, & Rosen, 2010; So, Seow, & Looi, 2009). Through such a cross-contextual trajectory, both the "idea" and the learning process itself are constantly "recontextualized," which would lead to deep learning.

Discussion

While the above research projects vary in orientations and research goals, the commonality that stands out among them is the focus on student-generated ideas as a cornerstone of the learning design. Students' ideas play multiple roles in the respective projects (e.g. as a targeted outcome in the development of learning tasks, target for intervention, resource for learning, data source, etc.). These roles can be organized according the cognitive, social and cultural aspects in the design of interventions (Kapur & Bielaczyc, 2012). By leveraging various types of students' ideas in several ways (e.g. as knowledge representations, language, strategies, decisions, design thinking), we offer our collective design principles embedded in the SGIs approach in Figure 1.

Design Principles for Student-Generated Ideas	
Cognitive	
Planning for and leveraging unpredictability...	Eliciting students' naïve representations of yet-to-be learned concepts allows teachers to better understand what students know and can guide their instructional moves accordingly. In order to do that, teachers must become comfortable with planning for the "unplannable," since they cannot know exactly what a student knows until the student shares it.
...by turning student errors into opportunities.	Teachers can oftentimes be quick to correct student errors for a number of reasons: fears that students' errors will "stick," discomfort with uncertainty, aversion to failure, and general habit/familiarity with being the "sage on the stage." However, allowing students to correct their own errors, struggle through failures, and manage uncertainty are powerful learning resources. SGIs provide opportunistic conditions that support students to do the hard work of struggling to overcome their own misunderstandings and to develop their naive representations.
Social	
Capitalizing on student dialogue.	The social opportunities in a learning environment are crucial for designs based on student-generated ideas. Conditions should be set up such that students can engage in natural and authentic conversation. It is not about imposing structures onto social experiences that direct students to discuss "the right things," but creating an atmosphere through the learning design that promotes the curiosity and motivation to talk through ideas, thoughts, and decisions with one another.
Cultural	
Perceiving ideas as a "means" and not an "end."	Although helping students to generate their own ideas in the first place is a noteworthy goal, the intent of SGIs is rather to use students' ideas as the means for (a) the student to improve understanding and meaning-making and (b) the teacher to facilitate the student learning process by basing instruction on the students' own representations. Students and teachers may not be initially comfortable with this perception and process, and so a classroom culture that supports SGIs may need to be developed.

Figure 1: Design principles for Student-Generated Ideas.

With student ideas at the forefront, our collective work addresses how approaches based on SGIs influence the learning mechanisms, knowledge outcomes, and socio-cultural surround in authentic settings. SGIs involve a process of ideating, e.g., through the generation of solutions/problems, elicitation of language, invoking "design thinking" through play and embodied experiences, and removing the "seams" of learning from the classroom to the informal environment. This symposium not only aims to fill gaps in the knowledge base, but also plays an active role in progressing the cultural shift towards student-centric instruction. Through distilling and sharing the core design principles around SGIs-focused learning approaches, this work contributes to important components to the learning sciences discipline and in changing educational practice.

References

Asterhan, C.S.C. & Schwarz, B.B. (2009). Argumentation and explanation in conceptual change: Indications from protocol analyses of peer-to-peer dialog. *Cognitive Science, 33*, 374-400.

Barab, S.A. & Plucker, J.A. (2006). Smart people or smart contexts? Cognition, ability, and talent development in an age of situated approaches to knowing and learning. *Educational Psychologist, 37*(3), 165-182.

Barron, B. (2003). When smart groups fail. *Journal of the Learning Sciences, 12*(3), 307- 359.

Chee, Y. S., Mehrotra, S., & Ong, J. C. (2014). Authentic game-based learning and teachers' dilemmas in reconstructing professional practice. *Learning, Media and Technology, 40*(4), 514-535. http://doi.org/10.1080/17439884.2014.953958

Cira, N. J., Chung, A. M., Denisin, A. K., Rensi, S., Sanchez, G. N., Quake, S. R., & Riedel-Kruse, I. H. (2015). A Biotic Game Design Project for Integrated Life Science and Engineering Education. *PLoS Biol*, *13*(3), e1002110. http://doi.org/10.1371/journal.pbio.1002110

Clark, A. (2001). *Mindware: an introduction to the philosophy of cognitive science*. Oxford, UK: Oxford University Press.

Clark, A., & Chalmers, D. (1998). The extended mind. *Analysis*, *58*, 10-23.

Csikszentmihályi, M. (1990). Literacy and intrinsic motivation. *Daedalus, 119*(2), 115-140.

Dillenbourg, P. (2002). Over-scripting CSCL: The risks of blending collaborative learning with instructional design. In P. Kirschner (Ed.) *Three World of CSCL. Can We Support CSCL?*, pp. 61-91. Open Universiteit Nederland, Heerlen.

Engle, R.A. & Conant, F.R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and Instruction, 20*(4), 399-483.

Finke, R. A., Ward, T. B., & Smith, S. M. (1992). *Creative Cognition: Theory, Research, and Applications*, Cambridge, MA: MIT Press.

Fischer, F., Kollar, I., Stegmann, K., & Wecker, C. (2013). Toward a script theory of guidance in computer-supported collaborative learning. *Educational Psychologist, 48*(1), 55-66.

Foster, A., & Shah, M. (2012). PCaRD: A model for teachers to integrate games in their classrooms. In *Society for Information Technology & Teacher Education International Conference* (Vol. 2012, pp. 2525–2533).

Frändberg, B., Lincoln, P., & Wallin, A. (2013). Linguistic resources used in Grade 8 students' submicro level explanations—Science items from TIMSS 2007. *Research in Science Education, 43*(6), 2387-2406. doi: 10.1007/s11165-013-9363-0

Games, A. (2008). Three dialogs: a framework for the analysis and assessment of twenty-first-century literacy practices, and its use in the context of game design within Gamestar Mechanic. *E-Learning and Digital Media*, *5*(4), 396 – 417.

Gaskin, J., & Berente, N. (2011). Video Game Design in the MBA Curriculum: An Experiential Learning Approach for Teaching Design Thinking. *Communications of the Association for Information Systems*, *29*(1). Retrieved from http://aisel.aisnet.org/cais/vol29/iss1/6

Gee, J. P. (2004). Language in the science classroom: Academic social languages as the heart of school-based literacy. In W. Saul (Ed.), *Crossing Borders in Literacy and Science Instruction: Perspectives on Theory and Practice* (pp. 13-32). Newark, DE: International Reading Association & National Science Teachers Association.

Goel, V. (2014) Creative brains: designing in the real world. *Frontiers in Human Neuroscience*. *8*:241. doi: 0.3389/fnhum.2014.00241

Hogan, D., Chan, M., Rahim, R., Kwek, D., Maung Aye, K., Loo, S. C., … Luo, W. (2013). Assessment and the logic of instructional practice in Secondary 3 English and mathematics classrooms in Singapore. *Review of Education*, *1*(1), 57–106. http://doi.org/10.1002/rev3.3002

Hung, D., Lee, S.-S., & Lim, K. Y. T. (2012). Authenticity in learning for the twenty-first century: Bridging the formal and the informal. *Educational Technology Research and Development, 60*(6), 1071-1091.

Kafai, Y. (2006). Playing and Making Games for Learning: Instructionist and Constructionist Perspectives for Game Studies. *Games and Culture*, *1*(1), 36.

Kapur, M. (2015). The preparatory effects of problem solving versus problem posing on learning from instruction. *Learning and instruction, 39*, 23-31.

Kapur, M. (2008). Productive failure. *Cognition and Instruction, 26*(3), 379-424.

Kapur, M. (2014). Productive Failure in learning math. *Cognitive Science, 38*, 1008-1022.

Kapur, M., & Bielaczyc, K. (2012). Designing for productive failure. *Journal of the Learning Sciences, 21*(1), 45-83.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, UK: Cambridge University Press.

Lewis, S., Pea, R., & Rosen, J. (2010). Beyond participation to co-creation of meaning: mobile social media in generative learning communities. *Social Science Information, 49*(3), 1-19.

Looi, C.-K., Seow, P., Zhang, B. H., So, H.-J., Chen, W., & Wong, L.-H. (2010). Leveraging mobile technology for sustainable seamless learning: A research agenda. *British Journal of Educational Technology, 42*(1), 154-169.

Moje, E. B. (2007). Developing socially just subject-matter instruction: A review of the literature on disciplinary literacy teaching. *Review of Research in Education, 31*, 1-44.

Norris, S. P., & Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education, 87*(2), 224-240.
Overmars, M. (2004). Teaching Computer Science Through Game Design. *Computer*, *37*(4), 81–83. http://doi.org/10.1109/MC.2004.1297314
Rummel, N., Spada, H., & Hauser, S. (2009). Learning to collaborate while being scripted or by observing a model. *Computer-Supported Collaborative Learning, 4*, 69-92.
Schoultz, J., Säljö, R., & Wyndhamn, J. (2001). Conceptual knowledge in talk and text: What does it take to understand a science question? *Instructional Science, 29*, 213-236.
Seah, L. (2015). Elementary Teachers' Perception of Language Issues in Science Classrooms. *International Journal of Science and Mathematics Education*, 1-20. doi: 10.1007/s10763-015-9648-z
Seah, L. H, Clarke D. & Hart C. (2015) Understanding Middle School Students' Difficulties in Explaining Density Differences from a Language Perspective, *International Journal of Science Education*, 37:14, 2386-2409, DOI:10.1080/09500693.2015.1080879
Shapiro, L. (2011). *Embodied cognition: New problems in philosophy*. Abingdon, Oxon: Routledge.
Sharples, M. (2015). Seamless learning despite context. In L.-H. Wong, M. Milrad, & M. Specht (Eds.), *Seamless Learning in the Age of Mobile Connectivity* (pp. 41-56): Springer.
Sharples, M., McAndrew, P., Weller, M., Ferguson, R., FitzGerald, E., Hirst, T., . . . Whitelock, D. (2012). *Innovating Pedagogy 2012*. Retrieved from Milton Keynes, UK:
So, H.-J., Seow, P., & Looi, C.-K. (2009). Location matters: Leveraging knowledge building with mobile devices and Web 2.0 technology. *Interactive Learning Environments, 17*(4), 367-382.
Van Eck, R. (2006). Digital Game-Based Learning: It's not just the digital natives who are restless. *Educause Review*, *41*(2), 16–30.
Walker, E., Rummel, N., & Koedinger, K.R., (2011). Designing automated adaptive support to improve student helping behaviors in a peer tutoring activity. *Computer-Supported Collaborative Learning, 6*, 279-306.
Wong, L.-H. (2013). Analysis of students' after-school mobile-assisted artifact creation processes in a seamless language learning environment. *Educational Technology & Society, 16*(2), 198-211.
Wong, L.-H. (2015). A brief history of mobile seamless learning. In L.-H. Wong, M. Milrad, & M. Specht (Eds.), *Seamless Learning in the Age of Mobile Connectivity* (pp. 3-40): Springer.
Wong, L.-H., Chen, W., & Jan, M. (2012). How artefacts mediate small group co-creation activities in a mobile-assisted language learning environment? *Journal of Computer Assisted Learning, 28*(5), 411-424.
Yore, L. D. (2012). Science literacy for all: More than a slogan, logo, or rally flag! In K. C. D. Tan & M. Kim (Eds.), *Issues and challenges in science education research: Moving forward* (pp. 5-23). Dordrecht: Springer.

Acknowledgments

We thank all participating teachers and students. This work was partially funded by the National Institute of Education and Ministry of Education in Singapore through the following grants:
OER 16/14 SLH; OER 06/15 RJL; OER 12/14 MT; OER 02/15 HJS; OER 14/14 WLH; OER 04/15 MG