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Building a learning progression for scientific imagination: A measurement approach

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ABSTRACT

This study aimed to build a learning progression (LP) for the development of scientific imagination based on a measurement approach using the BEAR Assessment System (BAS) in an attempt to better understand the core ideas and the developmental path of the scientific imagination process as well as align curriculum, instruction, and assessment through LP. Participants in this study were selected from Taiwan, and classified into two categories. The first category included 741 5th and 6th grade elementary school students, were administered the Scientific Imagination Test-Verbal (SIT-Verbal). The second category included one award-winning teacher who designed and implemented a set of curriculum for scientific imagination. The SIT-Verbal was developed by a panel of experts and covered four key components of scientific imagination process: brainstorming, association, transformation/elaboration, and conceptualization/organization/formation. The multiple validities of the SIT-Verbal were assessed using the Rasch partial credit model. Results showed that the components of brainstorming, association, and transformation/elaboration were hierarchical. Additionally, the SIT-Verbal was suitable for measuring students' scientific imagination at the elementary school level. Based on the proposed LP, a set of science curricula was developed for science classroom. The teacher's reflections and observations of LP application were recorded to provide insight into scientific imagination development in practice. The conclusion of the study not only enhance teachers' professions, but also provide more abundant information to verify the LPs for scientific imagination. Implications for the assessments with the LPs and revisions for both the SIT-Verbal and the scientific imagination LP are also proposed.

1. Introduction

Imagination and innovation are key elements driving the present economy and culture (McCormack, 2010). The development of technology today depends on implementing the best strategies for turning imagination into creativity (Vygotsky, 1930/2004). Many scientific theories and inventions have originated primarily from ideational processes within what is commonly referred to as the human imagination. For example, the 19th-century German chemist August Kekulé pictured the ring structure of benzene after dreaming of a snake eating its own tail; this discovery provided a solution to several difficult problems at the time, thus implying that dream images could translate into chemical reality (Robinson, 2010). In the classic

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Chinese novel *Journey to the West* set in the Ming dynasty, the Monkey King, Sun Wu-Kong, who created clones of himself from his own hair was echoed in the cloning of Dolly the sheep in the 20th century (Campbell, McWhir, Ritchie, & Wilmut, 1996). Another example is Albert Einstein, who having famously imagined himself flying at light speed and visualizing the objects that he might see, ultimately developed the theory of general relativity. The "invisibility cloak" in the Harry Potter series may become a reality, as metamaterials are currently being investigated by scientists (Pendry, Schurig, & Smith, 2006). As depicted in the examples provided, we 'see' through operational processes, manipulations, and interactions involving the imagination; a human being recognizes internally generated creative ideas that lead ultimately to the invention or design of concrete objects that are eventually manufactured into products (Eckhoff & Urbach, 2008).

Imagination has a great influence on people's thinking, language, and life experiences (Adams, 2004; Grant, 2004; Mountain, 2007). Processes stemming from human imagination potentially provide people with opportunities to explore the world, follow their interests, find answers to problems, and further develop capabilities that are necessary for future survival (Adams, 2004; Church, 2006; Grant, 2004; Mey, 2006; Mountain, 2007; Osborn, 1953; Vygotsky, 1930/2004; Zabriskie, 2004; Zhao, Hoeffler, & Dahl, 2009). Today's science education is the best opportunity for emphasizing imagination and innovation (McCormack, 2010). Infusing imagination into science education (e.g., student-centered scientific studies or innovation venues) would benefit the entire curriculum by deepening and broadening students' scientific concepts. Only by exerting imagination can we surpass existing knowledge and extend beyond the limitations of experience to produce new ideas for solving problems (Church, 2006).

In April 2013, the National Research Council of the United States created a framework for kindergarten through 12th grade science education, referred to as the Next Generation Science Standards (NGSS). Specifically, these standards are based on three dimensions: (1) disciplinary core ideas, (2) science and engineering practices, and (3) crosscutting concepts. The NGSS reflect an evolved vision of inquiry-based learning, emphasizing science as a knowledge-building endeavor. An improvement over prior science education standards, the NGSS is embedded in LPs research-based cognitive models of how learning of scientific concepts and practices unfolds over time (Duncan & Rivet, 2013). Moreover, in the NGSS report, one category in the appendix Nature of Science, "Science is a Human Endeavor," emphasizes the importance of imagination and creativity in different phases of elementary school grades 3–5, middle school, and high school (The Next Generation Science Standards, 2013). The importance of higher-order thinking skills, such as imagination and creativity, in science education grows and changes over time and requires attention from an early age.

In recent years, LPs have been widely discussed in science education. LPs are successively more sophisticated ways of thinking about a topic or big ideas over an extended period of time and can be used as templates for the development of curriculum and assessments (Smith, Wiser, Anderson, & Krajcik, 2006; Wilson, 2009). LPs have also been described as a conjectural model of learning over time that still requires empirical validation (Duncan, 2009). Recent policy reports and studies have advocated for the use of LPs as a means of aligning curriculum, instruction, and assessment (NRC, 2006, 2007; Smith et al., 2006; Wilson, 2009). Moreover, the Journal of Research in Science Teaching from the National Association for Research in Science Teaching (NARST) published a special issue about "Learning Progressions" in 2009 (Duncan, 2009). Thus, LPs studies have become an important trend among researchers worldwide, requiring extensive exploration from various cultural contexts.

More recently, LPs have been used to explore "the big ideas" in scientific disciplines. Examples include the food chain concept (Gotwals & Songer, 2010; Songer & Gotwals, 2012), biodiversity (Songer, Kelcey, & Gotwals, 2009), and genetics (Duncan & Tseng, 2011; Duncan, Rogat, & Yarden, 2009; Freidenreich, Duncan, & Shea, 2011) in biology; celestial motion in earth science (Plummer & Krajcik, 2010; Wilson, 2009); force and motion in physics (Alonzo & Steedle, 2009; Fulmer, Liang, & Liu, 2014; Steedle & Shavelson, 2009); matter in chemistry (Adadan, Trundle, & Irving, 2010; Liu & Lesniak, 2006; Johnson & Tymms, 2011; Stevens, Delgado, & Krajcik, 2010); and energy (Lee & Liu, 2010) and carbon cycling (Mohan, Chen, & Anderson, 2009) across disciplines. However, in terms of LPs, higher-order thinking is rarely mentioned in non-disciplines, with the exception of "scientific modeling" (Schwarz, Reiser, Davis, & Kenyon, 2009) and "scientific argumentation" (Berland & McNeill, 2010) in science education. In fact, imagination is an important issue in science field; for instance, scientific imagination is the desire to deal with inconveniences encountered in daily life, and problem-solving also depends on the operation of imagination (Ho, Wang, & Cheng, 2013). Therefore, the purpose of this study was to build a LP for scientific imagination based on the perspective of scientific invention in the informal activities of science education and attempt to understand the core ideas and learning paths of the scientific imagination process for primary school students through feedback from the LPs.

2. Building a LP for scientific imagination: alignment of curriculum, instruction, and assessment

2.1. Building a LP for scientific imagination: a measurement approach

In the past, most LPs researches (e.g., Alonzo & Steedle, 2009; Claesgens, Scalise, Wilson, & Stacy, 2009; Duncan & Hmelo-Silver, 2009; Mohan et al., 2009; Stevens et al., 2010) indicated that the development of LPs was an iterative process. In this process, the researchers first propose a hypothetical theoretical model of the LPs by exploring the main concepts in specific disciplines and reviewing the literature. Then, empirical data are collected to verify and modify the hypothetical model iteratively. Common methods for exploring LPs include exploring the different levels of students' understanding through assessment (Johnson & Tymms, 2011; Songer & Gotwals, 2012), clarifying students' level of understanding through interviews