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How creativity, autonomy and visual reasoning contribute to cognitive learning in a STEAM hands-on inquiry-based math module

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ABSTRACT

An informal mathematical module integrating Arts (modifying STEM to STEAM) and following an inquiry-based learning approach was applied to a sample of 392 students (aged 12–13 years). The three lesson module dealt with mathematical phenomena providing participants with the commercially available hands-on construction kit, aiming to advance STEAM education. Pupils built original, personal, and individual geometrical structures by using plastic pipes in allowing high levels of creativity as well as of autonomy. Tutors supervised the construction process and intervened only on demand. A pre-/post-test design monitored the cognitive knowledge and the variables of relative autonomy, visual reasoning, formal operations as well as creativity. Our informal intervention produced newly acquired cognitive knowledge which as a process was shown of being supported by a broad basis of (soft) factors as described above. A path analysis elaborated the role of creativity (measured with two subscale: act and flow) to cognitive learning (post-knowledge), when flow was shown to lead. Pre-knowledge scores were significantly influenced by both creativity subscales: act and flow. However, relative autonomy, visual reasoning and formal operations contributed, too. In consequence, cognitive learning within STEAM modules was shown dependent on external triggers. Conclusions for appropriate educational settings to foster STEAM environments are discussed.

1. Introduction

There is a lot of everyday knowledge supporting the new trend of enriching the STEM into STEAM education. One of the main approaches has been the adding of the elements of arts, skills, and creativity to the learning and teaching practices of mathematics especially in relation to other areas of knowledge and culture. However, there is only little evidence based studies to confirm these practical experiences. Thus, relevant and reliable research is urgently needed to expand the emerging STEAM movement and activities.

Learning by inquiry is assumed to follow the thinking paths of scientists. Rather than being told about science or just remembering facts, students are expected to learn how to think scientifically (Alberts, 2009; Faure et al., 1972; Gardner, 1991). Beyond the accumulation of disconnected facts, inquiry-based learning is expected to support some understanding of cause and effect, of relationships as well as of the power to predict, react and control (Illich, 1971; Others & Author, 2017a,b). This way of learning does not neglect individual knowledge, it also challenges individuals' everyday ideas about reality (Lakoff & Johnson, 1999; Tal, 2014). Learning follows the process by which scientists discover knowledge by collecting empirical evidence, by building upon critical analyses, by searching for independent confirmation and by integrating results from observations and/or experiments (*e.g.*, Driver,

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Leach, Millar, & Scott, 1996; Keselman, 2003; Kuhn, 2005; Burnard, 2015). Inquiry-learning may lead students to question and to share solutions, to extract valid conclusions from hands-on experiments, to formulate questions, to work with peers and to apply the usual research techniques (Lederman & Lederman, 2012; Scharfenberg & Bogner, 2013). Any inquiry process may integrate learning tasks, assessments, resources, environments, and teaching strategies, and typically may reflect commitment to student-centeredness and learner empowerment (White & Frederikson, 1998). Formal and informal settings may support higher-order learning experiences and lead to participation in scientific practices by using the discourse of science and working with scientific representations and tools (Rennie, 2014). Consequent hands-on experience might support observations (Oppenheimer, 1968) and lead to subsequent conclusions instead of offering occasional tours to such experiments (Salmi, 2003). Informal, open learning environments have also proved to be effective in learning mathematics (Vainikainen, Salmi, & Thuneberg, 2016). The integration of arts into STEM is supposed to reshape scientific education and humanities education, especially when further supported by problem-solving integration within trans-disciplinary frameworks (Salmi, Thuneberg, & Fenyvesi, 2017; Fenyvesi, Koskimaa, & Lavicza, 2015).

Scruggs and Mastropieri (1994) have shown that when students use hands-on methods they tend to enjoy learning more, to remember better and to consider hands-on as more effective for their learning than traditional classroom teaching methods, and especially as more efficient than learning only by seeing or listening. Teachers also rate the hands-on method as the most effective method (Ballantyne & Packer, 2009). Also, hands-on learning has been found effective for learners with learning difficulties (Brigham, Scruggs, & Mastropieri, 2011; Salmi & Thuneberg, 2017) or with more serious emotional disturbances (McCarthy, 2005). Informal, open learning environments have been proven as effective also for mathematics learning (Salmi, Vainikainen, & Thuneberg, 2015).

STEAM (Science, Technology, Engineering, Art, Mathematics education) can be defined as “education for increasing students’ interest and understanding in scientific technology and for growing STEAM literacy based on scientific technology and the ability to solve problems in the real world” (Kofac, 2017, p. 3)”. This definition has been one of the principles in successful education reforms in South-Korea. The definition is then operationalized into practical education by two key terms: 1. Education based on scientific technology, and 2. Ability to solve problems in the real world (Kofac, 2017). This same dilemma has been topic also in UK, where several attempts have been growing to broad the curricula towards a more responsive, dynamic, and also inclusive form of education. STEAM has been showing promising results in evidence-based practices (BERA-report, 2017).

The current STEAM initiatives may provide additional channels to learn abstract mathematical problem-solving tasks (BERA-report, 2017; Yakman & Lee, 2012). The interactive hands-on method in a workshop setting is assumed to encourage students to find creative solutions based on experimentation and observation, using the learning by doing principle (Dewey, 1938), which is important at the concrete operational stage (Piaget, 1977). The aesthetic elements of handicraft and art promote understanding of mathematical concepts by exposing students to concrete space and shape experiences (Dewey, 1980; Mack, 2006). Creativity as a supposedly complex construct comprises the difficulty to define and to quantify. As creativity (Burnard, 2015) is assumed to introduce new impulses into science education (STEM) and lead to better acceptance of science by adolescents, recent initiatives have proposed an integration of creativity (summarized in Arts), thus modifying STEM to STEAM. As creative processes are assumed to be complex, many studies contributed to prepare the field for quantification: Csikszentmihalyi (2000) defined two domains, the first was called “flow”, characterized by complete absorption in an activity: a person is regarded as fully immersed in a feeling of energized focus, accompanied with full involvement and enjoyment. Flow is perceived as linked to intrinsic motivation, particularly at young ages. Flow levels may tend to drop within knowledge-based classroom activities (Csikszentmihalyi, 2000). Act as the second pillar involved is covering conscious and trainable cognitive processes. Quantifying creativity of adolescents is following this two-pillar approach by following a Likert-scale questionnaire originated from Miller and Dumford (2016).

In consequence, our study had four objectives: First to assess the cognitive learning potential of participating students by monitoring pre- and post-knowledge levels; second, to identify the effect of visual reasoning, abstract thinking, experienced autonomy to predict the expected learning outcome; third, to characterize the influence of creativity in our STEAM-module; and finally to examine gender differences.

2. Methods and procedures

2.1. Participants

Participants came from the Helsinki capital area (N = 392), 52% girls (n = 204) and 48% boys (n = 188), age average 12 years and 4 months (Std.Dev. = 0.32). Altogether 11 schools contributed to our convenience sample. The study followed the empirical permission requirements and ethical principles.

2.2. Educational intervention

Our creative math & art workshop offered an opportunity to enrich traditional STEM into STEAM education. The pupils could build, test, explore and learn in small groups of 6–8 freely within a 3 × 45-minute time period. The workshop took place in an open learning environment of the university premises. The workshop followed the national curriculum obligations. At first, after a ten minutes introduction the concrete materials were presented providing the basic information about options of the creative hands-on construction materials. Two adults supervised as tutors mostly following, encouraging and providing information on demand. Pupils were encouraged to build their own structures by using the small plastic pipes and circles coming up with, for instance, machines, creatures, mobile equipment, or structures: They could produce, fabricate or create amusement. An overall plan was required