A Review of ACD-STEMM Integration

Part 2: Controlled Studies of Transdisciplinary Tools-for-Thinking Bridges for Arts-Science Pedagogy

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This is Part 2 of a three-part analysis of studies concerning useful ways in which visual, plastic, musical and performing arts; crafts; and design (referred to for simplicity as arts-crafts-design, or ACD) may be used to improve learning of science, technology, engineering, mathematics and medicine (STEMM) and increase professional success in these subjects.

Part 1 outlines eight "bridges" that STEMM professionals say they use to link ACD to their work and why they do so. Part 2 summarizes pedagogical studies that test the efficacy of Bridge 1 to find out whether ACD exercise of certain "tools for thinking" improves aspects of STEMM learning. Identified and described in Root-Bernstein and Root-Bernstein's *Sparks of Genius* (Houghton Mifflin, 1999), these cognitive skills play a vital role in creative problem-raising and problem-solving strategies shared by artists and scientists. The thinking tools include observing, imaging, abstracting, pattern recognition, pattern-forming, analogizing, modeling, dimensional thinking, empathizing or play-acting, kinesthetic or body thinking, playing, transforming and synthesizing.

Studies reviewed here are largely limited to those that are well controlled, often randomized and statistically validated. We found these studies by exploring a wide range of databases using specific keywords and by following footnotes and references from one publication to another. While only a limited number of well-controlled studies of ACD-STEMM pedagogical integration using "tools for thinking" turned up, overall these studies demonstrate significant benefits to teaching outcomes.

Observing. Observing can be defined as sustained attention to some phenomenon using any or all of one's senses. More than a dozen well-controlled studies demonstrate that ACD-based lessons in visual and aural observing result in improved STEMM education outcomes related to observational skills.

Imaging. Imaging refers to the ability to recall and mentally manipulate the look, sound, smell, taste and/or feel of things that are not actually present, whether those things were once experienced or are wholly supposed. More than a hundred well-controlled pedagogical studies demonstrate that ACD can dramatically improve imaging ability and STEMM learning outcomes such as test scores, class grades and retention of learned material.

Abstracting. Abstracting, another essential STEMM skill, involves eliminating all unnecessary information from a set of observations to leave essential elements or meaning. The few empirical studies of relevance to abstracting in STEMM pedagogy demonstrate that it significantly improves the learning of general principles and the transferability of knowledge to new problems but does not improve the learning of specific facts. Whether ACD helps train students to abstract has not been studied.

Patterning (recognizing and forming patterns). Patterning involves recognition and invention of organizing principles within a diverse set of elements. All STEMM hypotheses and theories are explicit statements of patterns. Nevertheless, little has been done in STEMM pedagogy to actively address pattern recognition and pattern-forming, and no well-controlled studies of the use of ACD to teach these vital STEMM skills exist. It appears that patterning skill is acquired passively, if at all, in STEMM subjects.

Analogizing. Analogizing involves the discovery and utilization of functional similarities between structurally different things. A handful of studies suggest that the formal use of analogies in STEMM teaching is highly effective, but no well-controlled studies of the use of ACD analogies in STEMM education exist. As with patterning, STEMM students seem never to practice the generation of their own analogies.

Modeling and dimensional thinking. Modeling involves making a simplified analog of a complex thing or process, magnifying or miniaturizing in order to apprehend and test properties. A related skill, dimensional thinking, involves translating between dimensions in space and time. The only formal study of the use of ACD-derived modeling skills to improve STEMM learning outcomes found highly positive results but was not well controlled. As with patterning and analogizing, STEMM students are rarely given a chance to invent and fabricate their own models.

Empathizing or play-acting. Empathizing (and related play-acting) refers to the ways and means of placing oneself in another's "shoes," experiencing the world from another point of view. A handful of well-controlled studies demonstrate that using ACD to help students "become" the things they study significantly improves their observational ability and analytical reasoning. More such studies are needed to explore how generalizable the approach might be.

Kinesthetic or body thinking. Kinesthetic awareness of body position, balance and movement, hand-eye coordination and gross motor control can be employed as a kind of physical thinking that proves essential for experimental research and invention. Body thinking and manipulative ability often go under the radar in traditional academic assessment, although they can correlate with practical understanding in STEMM subjects. Indeed, ACD practice has been demon-

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strated to give students an advantage in learning a wide range of experimental and clinical procedures.

Playing. Playing involves the enjoyable, risk-free exploration of physical and/or mental environments that incidentally develops skills and knowledge. STEMM professionals searching for new technical or theoretical possibilities often use play as a creative strategy. However, except for game-based learning (akin, but not equivalent, to strategic play), STEMM classrooms largely eschew play.

Transforming and synthesizing. Transforming and synthesizing integrate the entire mental "toolbox" just described. Mental images of concepts must be transformed into logical hypotheses expressed through diagrams and models that generate embodied experimental procedures yielding observations that fall into patterns expressed in some sensory-accessible form such as graphs or models. Only two well-controlled studies have been carried out regarding the use of ACD to improve these skills in STEMM classrooms. Both demonstrated improved learning, retention and transfer of knowledge to new problems. More study is required.

In sum, well-controlled studies of the pedagogical use of the various thinking tools are far more extensive for some tools (observing, imaging, modeling) than for others (abstracting, patterning, analogizing, body thinking, playing, transforming-synthesizing). Where there is good data, it invariably confirms the self-reports of STEMM professionals summarized in Part 1 of this study: Tools for thinking can provide valuable bridges between ACD and STEMM learning and practice.

A similar analysis of the remaining seven bridges that connect STEMM professionals to ACD is provided in Part 3 of this extended abstract.

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