A Review of ACD-STEMM Integration

Part 3: Controlled Studies of Additional Transdisciplinary Bridges for Arts-Science Pedagogy and General Conclusions

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This is Part 3 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 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 so do. Part 2 summarizes pedagogical studies that test the efficacy of Bridge 1 as to whether ACD exercise of certain "tools for thinking"—described by Root-Bernstein and Root-Bernstein in their book *Sparks of Genius* (1999)—improves aspects of STEMM learning. Part 3 analyzes whether the remaining seven bridges that enable STEMM professionals to utilize ACD professionally have similar pedagogical benefits.

Bridge 2. ACD-derived implements, methods and materials. Many physical implements (e.g. classical or electronic instruments, brushes, lathes, looms), methods of using them (e.g. visualizing or recording sound, lace-making, silk screen printing, annealing) and materials (e.g. sound, paints, plasters, thread, wood, metal) tie ACD historically to STEMM disciplines. According to highly successful STEMM professionals (see Part 1 of this analysis), any of these may form useful connections between ACD and STEMM practice. Unfortunately, we can find no formal, well-controlled studies of the pedagogical use of this bridge in STEMM education.

Bridge 3. ACD-generated phenomena. Sometimes artists, working as artists, discover or invent new phenomena that STEMM professionals have never encountered before, which then become the focus of STEMM research. The invention of perspective drawing and its broader application to anamorphic transformations are excellent examples of how geometry and the arts have fruitfully benefited each other. Indeed, because many STEMM educators draw upon these and other ACD-generated phenomena in their teaching, there is an extensive and robust literature about the connections. Yet again we find no well-controlled formal studies of the efficacy of this pedagogical approach.

Bridge 4. Novel ACD principles and structures. Artists working as artists sometimes discover basic principles underlying natural phenomena or invent novel structures in the course of their work. These principles and structures can and do provide valuable insights for STEMM professionals and even, in some cases, underpin Nobel-prize-winning research. However, the use of such principles and structures has rarely, if ever, been used for teaching purposes and never in well-controlled studies.

Bridge 5. Experience with the creative process. Some STEMM professionals have asserted that avocational practice of ACD helps prepare them to understand and utilize the creative process more effectively in their STEMM professions (see Part 1). We found only three sets of well-controlled or well-documented studies of how formal training in ACD-related creative processes impacts STEMM learning, all of which demonstrated clear benefits in terms of increased flexibility, improved learning outcomes and transferability of skills to new problems.

Bridge 6. Transdisciplinary aesthetic principles. STEMM professionals often utilize aesthetic criteria in the development and analysis of STEMM research. Only one well-controlled study has been carried out using ACD-based aesthetics to inform STEMM learning, but it reported highly significant effects: "Teaching for transformative, aesthetic experience fosters more, and more enduring, learning of science concepts. Investigations of transfer also suggest students learning for transformative, aesthetic experiences learn to see the world differently" [1].

Bridge 7. Mnemonic devices; recording and communication techniques. Tools and techniques that improve memory or the ability to record experience and retrieve knowledge and that enhance communication are highly valued in all disciplines. No surprise, the arts provide a good many methods of use to the sciences. These have been demonstrated by several dozen well-controlled studies to be effective across the complete spectrum of STEMM subjects.

Bridge 8. Recreation leading to re-creation. While many STEMM professionals describe their ACD-related activities in obviously utilitarian terms (Bridges 1–7), some view ACD as simple recreation, as a means of freeing their minds from professional ruts and concerns. Like play (a Bridge 1 thinking tool), recreation has no direct vocational role. However, both recreation and play can function indirectly as learning or problem-solving strategies, hence as re-creation. We found no formal studies of the use of play or recreation to improve STEMM learning.

We identify significant lacunae in the pedagogical research. The best and most abundant studies of ACD-STEMM integration are in the medical and engineering fields, mostly at the college or professional school level. A broad, but not deep, set of studies exist for college sciences but not for college mathematics. There is a paucity of well-controlled studies for K–12 students but also some outstanding models for future "gold standard" studies.

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Our review of attempts to utilize ACD as *nonspecific* potentiators of STEMM cognition (that is to say, as capable of *generally* benefiting IQ, or mathematics ability, or creativity) reveals their inevitable failure. Simply adding ACD in pastiche fashion does not improve STEMM learning. Integration based on connecting skills, materials, principles and processes does. Indeed, a handful of "gold standard" studies demonstrate that transfer between disciplines only works and works well when both teachers and students understand the point of bridging ACD and STEMM. Thus, the first step in any pedagogical integration must be to make explicit its specific purpose, its particular methods and its expected results, including how transfer is to be implemented and assessed.

The second step is to beware the limitations of any particular type of ACD-STEMM integration. Mnemonic devices improve acquisition and retention of specific knowledge but not the transfer of learning to new situations, whereas abstractions and analogies do not improve acquisition and retention of knowledge but do improve transfer and application of learning. Drawing can improve observing, imaging, patterning, modeling and many other STEMM skills but only if taught in such a way that the drawing skill connects with the particular learning goal.

The need for integrated learning cannot be overstressed. Real-world problems demand creative thinkers able to connect knowledge and know-how from many different fields into real-world solutions. Effective ACD-STEMM integration can pave the way for the kind of transdisciplinary education that can meet tomorrow's challenges.

Reference

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