Interdisciplinary perspectives to the development of high ability in the 21st century

Commentary to Don Ambrose's "Borrowing Insights from Other Disciplines to Strengthen the Conceptual Foundations for Gifted Education"

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Abstract
Ambrose posits that gifted education is mired in the conceptual folds of psychology with dogmatic trends spilling into its application in educational settings. In particular he calls into question issues of socio-economic fairness, epistemological entrenchments within the discipline, and the need to adopt an interdisciplinary approach that can make it relevant for the 21st century. Arguments are proposed for interdisciplinary frameworks to help Gifted Education move beyond its existing theoretical status quo, and to make it relevant for the needs of 21st century societies. Other disciplines such as philosophy, economics, and sociology, which became encumbered in dogmatism were able to develop as a result of being open to conceptual frameworks from other disciplines that helped scholars rise above dogmatic quagmires (Ambrose, Sternberg, Sriraman, 2012). We discuss an interdisciplinary framework for talent development within the macro context of the changing needs of societies. More specifically we give examples of interdisciplinary work arising within mathematics and mathematics education that have freed these disciplines from their foundations in logic and psychology respectively.

Keywords: interdisciplinary education; experimental mathematics; model eliciting activities; high ability; talent development; mathematics education; societal needs

Idea borrowing from other disciplines is not a new phenomenon. For example, analytic philosophy draws on the foundations of logic whereas continental philosophy relies on hermeneutic frameworks; Economics which was initially dependent on mathematical methods used in the natural sciences as its foundational base has increasingly moved to sociology and evolutional psychology as a way to explain macro processes and human choices; Even physics which was anchored in the deterministic mechanical Newtonian universe underwent a subsequent paradigm shift towards the acceptance of relativity and probabilistic statements in quantum mechanics for the position of particles. Similarly statistics, which notes its birth in probability, influenced by Francis Bacon's re-conception of science, and traditionally Bayesian in its approach, has broadened its bases to accommodate frequentist and subjectivist views (Chernoff & Sriraman, 2014). This suggests that ideas from other disciplines play a major role in expanding boundaries and overcoming dogma (Ambrose, Sriraman, Pierce, 2014).

Human beings are by definition ''interdisciplinary''. We are complex neurobiological organisms capable of juggling a wide array of tasks that intertwine the physical, psychological, inter-personal, intuitional, intellectual, cultural, and spiritual dimensions of being. Moreover, issues humanity faces such as climate change, health, environment, overpopulation, and so on are so complex that these problems cannot be solved by a single person or even a single discipline

(Sriraman & Freiman, 2010). Therefore, an interdisciplinary approach is a key element for any successful educational enterprise, which aims to prepare future generations to deal with the increasing complexity and interconnectivity of our world.

There are ambiguities in what constitutes interdisciplinarity or creativity across disciplines similar to the domain specific and domain general debate in cognitive science (Simonton, 2012). In other words, are the knowledge and skills we learn in one domain transferable to another domain? This debate echoes most when applicable to eminent contributions, i.e., can individuals with high ability make sustained and varied contributions at the helm of different disciplines? Ambrose's article is a culmination of previous work (Ambrose, 2003, 2005, 2006, 2012) that has explored different facets such as aspiration development and contextual influences with an interdisciplinary framework and points to different forms of "border-crossing" work. He states that:

> The degree of conceptual integration increases as an individual or a team made up of researchers from different disciplines moves from one end to the other of a continuum with multidisciplinary work fitting at the least integrative end, transdisciplinary work fitting at the most integrative end, and interdisciplinary work in the middle. (see Ambrose's article, this issue)

A part of the article is focused on debates within cognitive science on appropriate metaphors for the brain. The term "complex systems" is used for the phenomenon arising in any inquiry of human beings *in situ* society, and the need to move beyond rigid research frameworks. After all a student (high ability or not) does not exist in a vacuum encountering knowledge. Yet information processing metaphors played a major role in research on mathematical thinking and learning in the 1960s and 1970s whereby phenomena were reduced to condition-action rules. Four decades later models and modeling frameworks emerged as a redeeming research framework for mathematical thinking by realizing the relevance of *American Pragmatists* such as William James, Charles Sanders Peirce, Oliver Wendell Holmes, George Herbert Mead, and John Dewey. Lesh and Sriraman (2005) summarized this interdisciplinary trend as follows: (a) Dewey and Meade emphasized that conceptual systems (in our case: mathematical thinking and learning) are a human construct, but fundamentally social in nature; (b) Pierce emphasized meanings of these constructs tend to be distributed across a variety of representational media (ranging from spoken language, written language, to diagrams and graphs, to concrete models, to experience-based metaphors); (c) Dewey emphasized that knowledge is organized around experiences at least as much as around abstractions. Decision-making situations nearly always must integrate ideas from more than a single discipline, or textbook topic area, or grand theory; (d) James emphasized that the "worlds of experience" that humans need to understand and to explain are not static but products of human creativity are continually changing; (e) Dewey emphasized that, in a world filled with technological tools for expressing and communicating ideas, it is naïve to suppose that all "thinking" goes on inside the minds of isolated individuals (pp.10-12).

Problems known as model eliciting activities (MEAs), which arose from this framework have made sophisticated mathematical ideas hitherto the privy of a few, accessible to more students (Lesh & Sriraman, 2010). The effectiveness of MEAs have been documented for instance in

Purdue University's *Gender Equity in Engineering Project,* students' abilities and achievements were assessed using tasks that were designed to be simulations of "real life" problem-solving situations not emphasized in traditional textbooks or tests. Lesh, Kaput, & Hamilton (2006) reported that a broader range of students naturally emerged as having extraordinary potential, and surprisingly enough, these students also came from populations (females and minorities) that are highly under-represented in fields that emphasize mathematics, science, and technology; and this was true precisely because their abilities were previously unrecognized. In other words, MEAs resulted in a hitherto unknown cognitive diversity in the range of responses/solutions. Even in the domain of mathematics where deductive proof was the *sine qua non* for centuries, it has been replaced by experimental mathematics. At least since the age of written media, mathematicians have been off-loading formerly manipulatable objects with increasingly powerful notations, which encapsulate numerous subconcepts (and processes). For example, a category encapsulates notions of sets and functions. A functor encapsulates categories and morphisms. These are examples of highly abstract objects that have evolved as a result of increased sophistication in the use of mathematical language. Thus a student who wants to "discover" original results say in Analysis or Algebra faces the obstacle of first learning a language that increases in its notational complexity as they progress through undergraduate and graduate level coursework. Even simply posed problems such as those found in number theory books very often need sophisticated tools from homological algebra to provide any reasonable answers. On the other hand the approach of experimental mathematics proposed by Borwein (2009) challenges the mathematical community to re-examine the role of deductive proof especially in the light of the fact that computing (and digital) packages can assist in discovering new results as well as check all possible cases (for a proof).

> I believe that the mathematical community (appropriately defined) is facing a great challenge to re-evaluate the role of proof in light of the power of current computer systems, of modern mathematical computing packages and of the growing capacity to data-mine on the internet (Borwein, 2009, p.1).

More importantly the ontological orientation of the school of experimental mathematics is that students need to cultivate insight into "how" to find a mathematical result and convince themselves of its truth before becoming encumbered in epistemological issues of notation and deductive reasoning. Experimental mathematics not only builds on the ideas of George Polya on the heuristics of plausible reasoning, but also opens up mathematics as an interdisciplinary subject with ideas of experimental work borrowed from the natural sciences, aided by computer science. Ambrose alludes to the work of Byer (2007) on the nature of inquiry in mathematics and suggests "a form of dogmatism in which their minds are captured by *sterile certainty*--the imposition of somewhat artificial, unwarranted conceptual order on the constructs they are studying."

Some instructional approaches are particularly important in opening up disciplines in ways that might provide new avenues for access to populations who might otherwise be marginalized by the "school experience". Hersh (1991) points out that the enterprise of mathematics is organized, like many other social institutions, into a "frontside" and a "backside". Like restaurants, theaters, and libraries, mathematics is characterized by differential activity being carried out in two marked "regions of activity". On the frontside, mathematics is presented in finished form as precise, clear, ordered, and abstract. Progress is deductive and axiomatic, proceeding from givens to theorems and lemmas through chains of logical reasoning. Subregions of the frontside of any social institution are divided into classes (i.e. box seats versus balcony seats at an orchestra concert). Witness in mathematics the professional mathematician, the graduate student, the undergraduate student needing remediation in mathematics. In contrast to the frontside, the backside is "mathematics as it appears among working mathematicians, in informal settings, told to one another behind closed doors" (Hersh, p. 128). Here, mathematics is fragmentary, informal, intuitive, and tentative. Activity is characterized by failed attempts, inductive reasoning, competing and conflicting notation, and even disagreement. Here, the necessary skills are creativity, ingenuity, and a willingness to conjecture and to explore. Hersh (1991) argues that the duality of mathematics as a social institution functions as a preservation mechanism to the myths of unity, objectivity, universality, and certainty, in mathematics.

Hersh's (1991) characterization of mathematics is useful in that it helps us identify the stratification of mathematics as a social institution and the necessary pathways by which students access mathematical knowledge. Certainly the "frontside" of mathematics is the mathematics that most school children experience in the classroom, where, "The goal is stated at the beginning of each chapter, and attained at the end" (p. 128). Further, finished-form-mathematics leaves little room for creativity and inventiveness as it arrives to the student, like a finely-cut diamond, as something to only behold and to admire. The deductive, axiomatic nature of the "frontside" of mathematics naturally sequences mathematical instruction, building new knowledge on old, increasing in complexity and inter-dependence. One potential byproduct of this structure is the alignment of "content mastery" with ability in mathematics. One's ability to progress in the "frontside" of mathematics is directly linked to one's ability to master content, that is, to memorize and to regurgitate mathematics as an indication of mathematical intelligence. Surprisingly, such skill is little valued in the "backside" of mathematics where brilliancy is aligned not with repetition and replication but rather with creative and inventive thought applied to inherently open-ended settings. But, as Hersh (1991) points out, initiation to the "backside" occurs only at the end of the mathematics education delivery structure, that is, in graduate school, typically in a dissertation study.

One must ask if entrenched social structures, like the one that Hersh (1991) describes, have a marginalizing effect on the development of high-ability students in the 21st century. Accepting the affirmative answer, one must search for a remedy to the situation. Again Hersh's (1991) metaphor is helpful. The deconstruction of the frontside/backside duality of mathematics as a social institution depends on the incorporation of "backside" mathematics in regular instruction. Rather than reserve open-ended, investigative, and creativity-dependent mathematics experiences for only those at the highest levels of study, integrate such experiences across the curriculum so that all students gain access to authentic mathematical experiences heretofore denied them.

Another theme in Ambrose's article warranting comment is changing STEM (Science, Technology, Engineering and Math) education into STEAM education by incorporating Arts as a vital interdisciplinary link. Gifted Education has placed an over-emphasis on the development of ability in STEM disciplines which tend to marginalize students who do not fit into traditional curricular trajectories of math-science in schools. Disciplinary boundaries and tensions that came out of the Renaissance, namely natural philosophy, art, alchemy (metallurgy/chemistry), theology as the first rupture continues today in the modern day antipathy among the ever increasing subdisciplines within arts, science, mathematics, and philosophy. Many of the thinking processes of polymaths who unified disciplines are commonly invoked by artists, scientists, mathematicians, and philosophers in their craft albeit the end products are invariably different (Sriraman and Dahl, 2009). These disciplines explore our world for new knowledge. For instance, literature is an excellent medium to create frequent shifts in perspective. Paradoxes can be easily investigated by exploring geometry motivated by Art. After all Art suggests new possibilities and pushes the limits of our imagination, whereas science verifies the actual limitations of these possibilities using mathematics. Models and Theory building lie at the intersection of art-science-mathematics. The history of model building in science conveys epistemological awareness of domain limitations (Root-Bernstein, 1996). Arts imagine possibilities, science attempts to generate models to test possibilities, and mathematics serves as the tool. The implications for gifted education today is to move away from the post Renaissance snobbery rampant within individual disciplines at the school and university levels by using interdisciplinary approaches that make math and science more accessible (Sriraman and Dahl, 2009).

Our final comment is on sections of Ambrose's article which suggest interdisciplinary approaches to address *epistemological pluralism* and *cognitive diversity*. The promulgation of such an approach rests upon the actions of future teachers. The actions of future teachers rest upon the beliefs teachers hold as to "what counts" as good mathematics instruction. These beliefs are formed primarily through experiences in mathematics classrooms. Given the "status quo" stabilizing nature of the K-12 school mathematics culture, hope for the reorganization and renovation of mathematics instruction rests solely upon those who are in possession of the knowledge that Ambrose has collected and shared, that is, upon teacher educators. While some research has demonstrated that the incorporation of interdisciplinary educational experiences promoting epistemological pluralism and cognitive diversity as part of teacher education can have an expansive effect on future teachers' beliefs about mathematics and mathematics instruction (i.e. Roscoe & Sriraman, 2011) much work remains to be done to support and to sustain the enactment of these beliefs in the classroom. While the renovation of teacher beliefs is an important starting point for the vision that Ambrose has collected, real challenges lie ahead in terms of professional development, curriculum development and, perhaps most importantly, financial remuneration to support change.

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