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For Female Leaders of Tomorrow: Cultivate an Interdisciplinary Mindset

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***Abstract*—The call for empowering women to participate fully in all sectors of society posits that women's participation is key to economic growth, political stability, and social transformation. Approaches to achieve such participation, however, are trivialized due to existing gender biases and women continue to lag behind in STEM professions. In this article I argue for the transformative power of an interdisciplinary mindset – particularly one engendered by a STEAM education whereby 'A' stands for Arts– as a catalyst for STEM careers and beyond. Furthermore, I conclude that STEAM will prevail in the hands of interdisciplinary leaders.**

***Keywords*—STEM, STEAM, interdisciplinarity, project-based learning, mentorship, empowerment, leadership, cognitive sciences, arts, pre-university and university education**

I. Introduction

From artificial intelligence to climate change to genome editing to big data we have arrived at an era where major societal questions and problems are related to and dependent on a myriad of intertwined factors. As a result, solutions cannot be found via a simple atomistic and linear perspective. Instead, solutions must be generated via the integration, interaction, and transformation of multiple disciplines. This implies that solution finders/problem-solvers must have a holistic, interdisciplinary mindset. And what does this mindset entail and how does it arise? As I will discuss in this paper, a holistic, interdisciplinary mindset refers to an agile thinker and doer capable of critical and creative thinking in various disciplines. Moreover, such capacity arises through its long-term cultivation in experiential, inquiry-based discovery and learning situations within education and workplace environments. The demand for encouraging and teaching such a mindset within STEM field curricula is current and rising [1], [2]. Moving boldly away from STEM and towards STEAM, whereby 'A' stands for the Arts, I delineate the transformative power of a STEAM education in promoting not only critical and creative thinking, but design, storytelling, and technical skills within multiple disciplines. As a leader and effective agent of change transformed by STEAM, I provide case studies of unique educational examples I have created that have led to the empowerment of young learners (specifically those in the pre-university and university years). I conclude with a proposal for significant changes in STEM education for policymakers.

A. *Empowering Women*

A critical role of leadership within the management and education sectors is *empowerment*. One of the more nuanced definitions of empowerment that addresses the potentially powerful guidance-and-learning relationship between a supervisor or teacher and a subordinate or student highlights the importance of the subordinate/student perceiving (i) meaningfulness, (ii) competence, (iii) self-determination, and (iv) impact in their work as a consequence of their supervisor/teacher's behavior [3]. As a young woman myself who is a rising scientist-artist and entrepreneur changing the face of empirical research design, science communication and public engagement, and revolutionizing brain science education, I know first-hand both the importance of having an older female role model who empowers and the imperative to taking responsibility in one's own hands as the empowered one leading change.

Much of the current discussion surrounding STEM fields circles around the vastly overdue and urgent need for female inclusion and overall female empowerment [4], [5]. This suggests that we as a society need to not only vigorously encourage and support more girls and young women into all types of STEM careers, but actively promote women throughout the entire career pipeline from early education to leadership positions within all STEM fields. A quick glance, for example, at the dismal percentage of women, 11% to be exact, running short courses on the latest advancements of electronic imaging at the IS&T International Symposium on Electronic Imaging Science and Technology in January-February, 2018 is disconcerting and underscores the persisting paucity of women within higher levels of STEM professions. Some argue it is not only a career pipeline but a bias barrier issue as well. A report produced in 2016 by LeanIn.Org and McKinsey & Company revealed that the climb up to top executive-level positions for women in corporate U.S. America, for example, is deeply rooted in prevailing gender biases regarding women's personalities and their abilities, and changes moving forward to rectify the problem must proactively face those biases, take responsibility, and commit to gender equality [6]. This brings up other issues, specifically those about *mentorship* and *opportunity*. To move from schooling to professional work to an agent of change requires a set of unique skills, irrespective of discipline or gender, beyond academic competency that are not taught in one or two-day motivational workshops or even in a semester course, but rather, are nurtured over time.

Learning by example via side-by-side guidance of an older expert in a field is one of the oldest techniques in trade learning/vocational education [7], [8]. Apprenticeships dating

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back to the Middle Ages were work environments where an apprentice/student/employee learned the nuances of a craft through direct on-the-job skills training with their master craftsman/teacher/employer. Espousing a similar paradigm, achieving success and a sense of empowerment to implement knowledge learned into impactful action requires side-by-side mentoring. In this mentoring situation, the mentor serves as a role model for the mentee to develop the skills of their trade as well as develop confidently and professionally to excel and eventually become a mentor themselves. For such a relationship to be fruitful, the mentor must have the following qualities that I separate into two categories, 'Skill Set' in Fig. 1 and 'Character Traits' in Fig. 2.

TABLE I.

Skill Set
(i) In-depth knowledge in focus area and related disciplines
(ii) Deep knowledge in at least one other discipline outside of focus area
(iii) Career success as evidenced by quality of accomplishments
(iv) Effective communication abilities for teaching and outreach
(v) Sociocultural savviness within the focus area
(vi) Efficient adaptability to new and spontaneous situations

Fig. 1. List of skills a mentor should possess to be effective.

TABLE II.

Character Traits
(i) Self-confidence in abilities both of the present and of the future
(ii) Personal satisfaction with accomplishments
(iii) Enthusiasm for the encouragement of others to learn, excel, and develop their intellectual capacities and voices as promoted by financial, emotional, and/or social support
(iv) Open-mindedness with respect to others' perspectives whether at the intellectual, cultural, and/or professional level(s)
(v) Eagerness and stamina towards advancing positive change despite roadblocks and setbacks
(vi) Receptivity to the unknown

Fig. 2. List of character traits a mentor should possess to be effective.

Being exposed to and engaging with a female mentor of such caliber explicitly demonstrates to the mentee that "if she [my mentor] could do it, then I *too* can do it and she can teach me the ropes –all the while adapting to my current needs. I'm not alone in this journey because she understands it well and has explicitly paved the path for us younger generations." Furthermore, the mentor acts as an intellectual catalyst for the mentee to gain a new perspective or set of perspectives otherwise not discovered and to desire to emulate her mentor. As a researcher, communicator, educator, and leader with the above skill set and character traits, I have taken the reins, so-to-speak, in my own hands and been in a position to effect change despite bureaucratic and institutional barriers. In the sections that follow, I discuss how I have merged my expertise in both the Sciences and the Arts to advance an experiential teaching paradigm that motivates multidisciplinary exploration, inquiry, and discovery and sets the intellectual foundations for interdisciplinary thinking. The results are impactful learning, action, and leadership.

II. The Case for A in STEM to Yield STEAM

A. *Pushing STEAM into Science Research*

STEAM, or the use of the Arts and design principles within STEM is a way of thinking that crosses the educational, research policy, and workforce arenas [9], [10]. Championed and publicized by the then president of the Rhode Island School of Design, John Maeda, the STEAM movement was spearheaded in 2008 under the idea that innovation arises via the merging of science disciplines with art disciplines. It is, in essence, the societal rebirth of the Renaissance and a concept I have followed my entire educational life.

Aside from being a trained and professional scientist, I am also a trained and professional artist. I am a scientist-artist working to understand creative thinking and human intelligence more broadly for the purpose of having a direct impact on the development of human-like intelligent machines in the near future. To achieve this goal I have conducted empirical research through my company, La Petite Noiseuse Productions, on the theoretical assumption that to fully understand human cognition any experimental work on the issue must integrate ecologically valid multi-sensory information in as realistic a context as possible. Moreover, we cannot underestimate the value of understanding the nuances of human behavior if they are to be modeled and integrated accurately within robotics and human-computer interfaces. As such, I have brought in the visual, literary, and performing arts within my cognitive behavioral research and created a hybrid science-art platform that merges questions, theories, methods, and data from the Sciences with questions, theories, methods, and products from the Arts. I am particularly interested in how natural language, musical improvisation, and emotion perception and cognition interrelate during spontaneous ideation and problem-solving and decision-making processes.

These hybrid scientific-artistic experiments, see visual examples shown in Fig. 3, have revealed that improvisatory creative behavior is the merged result of mini spontaneous decision-making moments that are dependent on stored knowledge, changing foci of attention, emotional targets, an openness to unexpected elements within an environment, and a quickness to perceiving the positive value of those unexpected elements. Moreover, the larger the improviser's knowledge toolbox from which to pull ideas is, the greater the number of possibilities for innovative actions. This further encourages the willingness to enter into an unforeseen direction of discovery that is contextually expected yet novel in its representation [11], [12], and [13]. Important to note is that such processes are analogous to other situations that require immediate problem-solving and decision-making behaviors and, if fully understood, can have significant impact on the development of machine algorithms that must integrate such for improved human-machine effectiveness, efficiency, and safety, e.g. automated driverless cars [14]. Since these experiments are conducted in front of a live audience, these works have also doubled as unique science communication platforms. The result has been overwhelmingly positive with the platform encouraging original and highly engaging conversations with audiences of all ages and educational backgrounds about Science, Art, Science-Art integration, and the future of interdisciplinary perspectives.

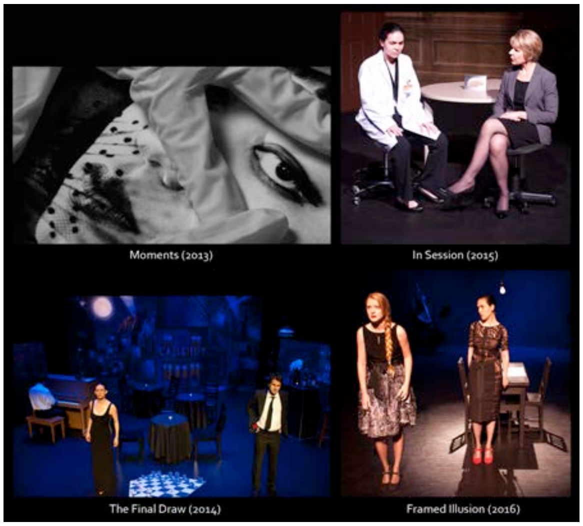

Fig. 3. Photo stills from one film and three theatrical productions that were specifically created for data acquisition and produced for live audiences. The data acquired are the musical sequences improvised by musicians reacting in real time to the actors' dialogue, behavior, and overall scene dynamics occurring on film or on stage.

This invention of a new conceptual paradigm for both empirical cognitive and computational research and science communication has even more far-reaching consequences; namely, for STEM education. An advocate for mentors leading by example and demonstrating that what works in theory must also work in practice, my Science-Art work directly informs my mindset as an educator. More specifically, I implement these experimental findings in the classroom as a way to teach one-of-a-kind creative thinking and doing in learners. It is no coincidence that I study creativity via a merged Science-Art perspective as much as I encourage, guide, and praise creativity and Science-Art integration in the classroom. I discovered my interest in the meaning and purpose of our human creative capacity because of all the inventive expressions I had been exposed to since childhood, whether scientific, technological, or artistic. Then as I delved into the study of the mind/brain, computational, and behavioral sciences in search for a well-rounded answer, and finding none, I was further intrigued. Now, as I take part of the research efforts towards making human-like machine intelligence a not-so-impossible reality, we as a society are (re)discovering the fundamental yet most complex makeup of our humanness: our emotion-driven improvisatory ability to ideate and invent novel solutions and actions in response to our changing environment. So why not nurture this innate ability during the learning process and help learners acquire an even larger intellectual toolbox to maximize their knowledge acquisition and creative potential!?

B. *Transferring the STEAM from Research into Education*

From the beginning of my career as a communicator and educator I have used the Arts as both a topic of study and a method of inquiry to engage with and teach students, professionals, and the general public the big and small questions of cognitive science and its sub-disciplines (anthropology, computer science, linguistics, neuroscience, philosophy, psychology). I took the leadership reins midway through graduate school in response to the non-interdisciplinarity, fact-based, and test-driven learning I had received during my undergraduate years and was receiving in my graduate program. I pioneered and taught my first interdisciplinary course in 2009 at Johns Hopkins University and have continued to the present with a portfolio of courses at the pre-university, university, and postgraduate levels that integrate my *reseARch scienTIST* polymathic skills and overall Science-Art advocacy as disciplines with remarkably similar questions and processes. The results have been an unprecedented opportunity for students from engineering to humanities disciplines to ideate, design, analyze, produce, present, and communicate hybrid Science-Art projects that involve as much research, experimentation, and paper writing as scriptwriting, storyboard designing, and moviemaking. In essence, fluidity between disciplines as marvelously espoused by Leonardo da Vinci.

C. *Case Studies: Interdisciplinary Courses*

The primary goal of my courses has been to teach students to be curious, critical and creative thinkers and problem-solvers with the knowledge and skills to tackle any discipline they may choose. I follow a learner-centric approach that focuses on experiential hands-on learning as resulting from the production of a creative solution to a real-world question or problem. While in line with the problem-based learning (PBL) approach common in the medical and engineering sciences [15], my approach is through the merging of Science and Art. This necessitates guiding students step-by-step to lay down a conceptual foundation in various interrelated disciplines, i.e. the behavioral, brain, cognitive, and computational sciences. Then, guiding students step-by-step to use the arts (i.e. film, literature, music, and photography) as both a source of inquiry and as a platform to progressively build complex and interconnected linkages between information. The result is a mix of theories, questions, methods, techniques, data, and products that are learned, created, and shared with the class. In every course I encourage each student to pick a related topic of their choice for their projects to maximize interest and motivation and variety of subject matter. This teaching paradigm invites the inevitable: inquiry, imagination, designing, exploration, trial and error experimentation, understanding, problem solving, discovery, collaboration, and communication. Such experiential STEAM courses are:

- *BMore: Charm City Thru the Lens* – On documentary photography and aesthetics and what the art form and its technology reveal about visual perception and cognition. Students read critical, experimental, and theoretical articles, participate in field trips to different neighborhoods in the city, write artist statements, and create photographic portfolios with their own photographs.

- *Mind, Brain, and Beauty* – On the visual and auditory systems, language, and computational creativity, and what the mind/brain reveals about visual art and music perception and cognition and intelligent machines. Students read critical, experimental, and theoretical articles, write research proposals, and create visualizations in the form of cartoons, infographics, or animated shorts.

- *Topics in Music Cognition* and *Introduction to Music Perception and Cognition* – On the auditory system and creativity, and what the mind/brain reveals about music perception and cognition, intelligent machines, and medical/clinical applications. Students read critical, experimental, and theoretical articles, write research papers on hypothetical experiments, create short films (documentary, drama, or experimental) or news podcasts, and write popular science articles, newsletters, blogs, or film essays.

- *Neuroscience Applied: Designing and Communicating Theory and Research* – About biological, brain, behavioral, computational, and medical science applications outside of the traditional academic laboratory setting. Students read critical, experimental, and theoretical articles, write research papers on hypothetical experiments, and create visualizations in the form of cartoons, infographics, or animated shorts.

- *Minds and Machines* – About the history of robots and intelligent machines and its representation across time in literature of the world. Students read a handful of short stories from around the world, write their own short stories or scripts, and design storyboards.

- *Surrealism* – About the Surrealist movement of the 1920s and the interrelationship between the brain and psychiatric sciences and technology and art theory, culture, and politics. Students read critical, experimental, and theoretical articles, write research papers, and design an artwork (painting, drawing, poem, or musical composition) in the Surrealist style.

Work is evaluated on students' grasp of foundational concepts and theories and their creative ability to question, experiment with, and transform the course's material. Evaluation is divided into three different areas: participation in group round-table discussions, individual in-class writing assignments, and creative semester-long projects. As such, all of these courses emphasize and require full conceptual *understanding* of facts over *knowing* facts. Students' *understanding* results from the active and experiential acquisition of information, its comprehension, transformation, and real-world application as they engage in critical conversations, analyses, and creative interpretation of the course's material. Moreover, students are empowered by a solid interdisciplinary knowledge base and a set of technical and creative skills applicable and transferable to any professional domain. Such practical real-world skills include: science research methods, multimedia styles and techniques, and science-art communication and presentation formats. Example student work in Fig. 4 was created during an in-class workshop on creative science visualizations, and Fig. 5 and Fig. 6 show improvised visualizations created for an in-class writing assignment with twenty minutes of allotted time. Students were aware of the assignment to be completed in class but were not told beforehand that it would entail the use of cartoons. Instructions were: *Given what we discussed last class and what you read for today, create a visualization that summarizes the main question(s), result(s), and conclusion(s) of the assigned reading. You may use cartoons and/or infographics. Make sure your piece has a narrative and assume your audience has not read the assigned reading.*

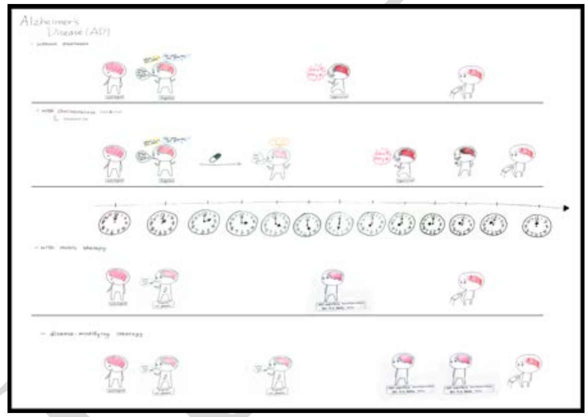

Fig. 4. Original improvised cartoon created by high schooler YY for their final project during an in-class workshop on science visualizations.

Fig. 5. Original improvised cartoon created by undergraduate student MA during an in-class writing assignment.

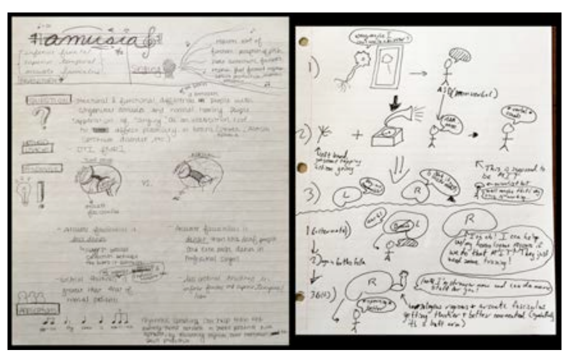

Fig. 6. Original improvised cartoons created by undergraduate students SC and IM, respectively, during an in-class writing assignment.

While the use of cartoons and a narrative structure are spontaneous and improvised, the motivation to be creative is not. These assignments are done within an environment I have explicitly set up for learners to be curious, imaginative, expressive, and inventive and consequently rewarded. Example student work in Fig. 7 and Fig. 8 show the variety of products created for their semester-long creative project assignment.

Fig. 7. Published research work, popular science articles, and short film program notes created by undergraduate students [16].

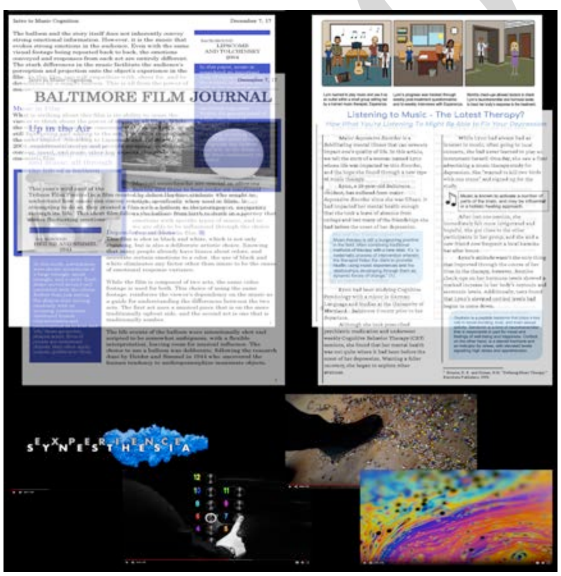

Fig. 8. Top row: newsletter and popular science article by undergraduate students DM, ST, & DU, and TL, IM, & TS, respectively. Bottom row: screenshots from a short film by undergraduate students SC, AN, BP, & TS.

III. Empowering by Proliferating STEAM Education and Interdisciplinary Mindsets

As mentioned earlier, empowerment comes when a student/mentee perceives the following four qualities in their work: (i) meaningfulness, (ii) competence, (iii) self-determination, and (iv) impact. All of these four qualities have been observed after taking the above courses. Aside from comments made to me at the end of the course, students' work speaks for itself. They not only know the main questions, theories, results, and solutions of the course's main topic, but also how to think in a creative interdisciplinary way because they have actively thought about and carried out other disciplines' questions, methods, and practices through a variety of open-ended and integrated assignments within a single course. In other words, I have given them mentorship and the opportunity to think and act in an entirely different manner than expected in typical educational settings. Additionally, I have uniquely given learners the unified intellectual framework for *why* and *how* disciplines are and can be further integrated. In support of the impactful learning results from these courses, research studies have demonstrated that students who are actively engaged in their learning –usually through experimentation, problem sets, projects, and the like– result in significantly greater levels of understanding and knowledge retention and transfer than those taught with traditional methods (i.e. lectures, labs) [17]. All of this underscores the power of interdisciplinary thinking and doing to empower a learner. Moreover, such interdisciplinarity sets the stage for proactively finding solutions for change within STEM, STEAM, and beyond. From what I have discussed here not only from my work as an entrepreneur but as an educator, impactful leaders are polymathic figures who expertly merge, twist, and transform a variety of knowledge domains and skill sets to constantly adapt to incoming challenges. It is this polymathic ability that has led me to become the visionary and leader that I am today. What we leaders must do is continue to be the mentors of tomorrow's leaders and take charge over the change we want to see by being the very example of such. Furthermore, we must directly sponsor activities that engender polymathic growth and actions.

A. Moving Forward

- The very notion that Science and Art are disparate disciplines needs to end. Science *is* an Art form and only a paradigm shift of thinking accepting its fluidity of process, production, and presentation with that of the Arts will lead to full assimilation of the Arts within Science and the Sciences within Art [18].
- Even if it means radical replacement of the old with the new, institutions from kindergarten to higher education need to offer real interdisciplinary opportunities to their students, not just labels of such. The data are available and persistence of non-interdisciplinary perspectives is slothful and unacceptable.
- In the absence of a polymath expert and professional in various disciplines to teach such courses as listed above, more team-taught courses between a scientist and an artist as in [19] should be required. Lexicons will be different

between disciplines and challenges will arise regarding methods, outcomes, and criteria for evaluation, but surviving among changing times is all about adapting accordingly.

- Between STEM and STEAM fields, engineering must coexist with the cognitive sciences and the arts. As noted in [14], [20], and [21], any design or machine built for human use and interaction must consider how humans think and behave. Moreover, as discussed in [14], as long as we are dealing with human-made and human-related problems, designs, and solutions, significant parallelisms exist between the arts and all other sectors. As such, the complexities of human cognition cannot be ignored and must be integrated. Merging questions from cognition with artistic outcomes and design problems, for example, can accelerate design performance, creating a more effective, efficient, and aesthetic environment in which to live with machines.

- The urgent appeal for interdisciplinarity is not only within education but also within the professional arena as well. Beyond mentorship, opportunity for out-of-the-box thinking and doing must be offered and rewarded. And the appropriate leaders to head such structural changes are the polymathic visionaries who have already connected supposed disparate dots and are already making new ones.

I conclude with a recent set of happenings because it sums up what I have just discussed. During a Q&A with the audience after one of my company's latest theatrical productions, a Q&A after giving a talk at an international science conference, and on the last day of class for one of my courses, I was asked the following: "With such disciplinary silos in education and within institutions in general, how exactly have you been able to arrive at such a complex and comfortable state of intersection?" I responded in all three instances with: "*The bottom line is that I've never made a distinction between Science and Art. In my mind they've always been a single discipline with a wide-ranging toolbox. I was encouraged from childhood to play with notes and words as much as with test tubes and numbers. It's the lack of boundaries that set me free - I could then, and even more so now, twist and pull those words and numbers into colors and states without offense. And what do I find? What I'm unafraid of finding. The unimaginable!*"

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