Beyond Boundaries: A Narrative Inquiry on Learning "Togetherness" in Scientific Education

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Introduction

Over the past 20 years, there has been growing interest in science, technology, engineering and mathematics (STEM) education in Europe, the United States, and beyond. The inherent connection between these disciplines is obvious as we engage in our world. We need look no further than nuclear weapons, flu shots, cancer treatments, high speed railway, or space travel to see evidence of this synergy. Knowledge of and about these disciplines is integral to preparing our population to be actively engaged and responsible citizens, creative and innovative, able to work collaboratively and stay fully informed with respect to the complex challenges facing society (European Commission, 2015; Man, Goździk & Korda, 2016).

Historically, scientific education has been an *élite* training (Man, Goździk & Korda, 2016), resulting in limited motivation and desire to learn, two driving forces of Adult Education (Knowles, Holton & Swanson, 2005). The pervasive lack of collaboration (and so togetherness) in scientific careers and curricula has contributed to the reckless usage of scientific and technological discoveries and led human beings toward non-empathetic behaviors (the atomic bomb, the electric chair, the nerve gas etc.), instead of more responsible applications (Dossey, 2010). Despite increasing global awareness of the need for interconnectivity among knowledge domains to promote lifelong learning (Milana & Holford, 2014), scientific disciplines are still taught in a manner disconnected from people's lives (Man, Goździk & Korda, 2016). This separateness and aloofness between learners and the science content is a repudiation of the relational, embedded, networked way learners view their place in the world (Gess, 2015).

With societal advances and notable shifts in international power, the global labor market necessitates movement of the educative fields of the aforementioned disciplines toward a substantive change, with aims to educate more flexible students (as future professionals) in learning skills to face the newest challenges. Specifically, two of these skills are *collaboration* and *transdisciplinarity*[3] (DTI, 2015).

What is STEM/STEAM education?

The acronym STEM is commonly used to refer to the separate disciplines of science, technology, engineering and mathematics (Breiner, Harkness, Johnson & Koehler, 2012), with reference to no interconnections. Recently, the intentional addition of Arts (ie: STEAM) to STEM classroom presentations has been shown to result in increased student motivation, engagement, achievement within STEM disciplines (Becker & Park, 2011), improve overall learning among STEM disciplines (Henriksen, 2011; Henricksen & Mishra, 2013) and favor the inclusion and persistence of students who are historically underrepresented in STEM disciplines (women, minorities, youth of low income families, immigrants, and students with disabilities) (Posner & Patoine, 2009).

The definitions of literacy for each STEAM discipline, while individualized, clearly overlap. Each cite depth of knowledge, interrelationships and problem application of knowledge as essential parts of becoming literate. Science, technology, engineering and arts take it a step further by pointing toward the necessity of

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[3] Transdisciplinarity refers to knowledge and skills that transcend and unify different disciplines. It requires the integration of problem solving, problem framing, communication and collaboration that cross organisational and disciplinary boundaries, in addition to disciplinary skills to meet demands for a growing education (DTI, 2015).

knowledge acquisition for the purpose of societal applications. Nonetheless, there exists a disconnection between how the subjects are *taught* and the way that professionals in the above-referenced disciplines actually *think* and *act* (Man, Goździk & Korda, 2016). Additionally, the subjects are persistently taught as separate disciplines to students (Katehi, 2009).

In the European Union (e.g. Portugal, Ireland, United Kingdom), as well as in the United States, innovative strategies have been created to attract adult and young people in lifelong learning (Man, Goździk & Korda, 2016). Education professionals, in concert with political leaders are now calling for teachers to intentionally present the aforementioned disciplines (STEM/STEAM) together in an effort to close the learning gap and better prepare students to succeed in a world yet to be imagined**.** Perhaps, in order to achieve this design-based educational context, educators should consider embracing an Integrative STEAM educational approach (I-STEAM) in their K-16 classroom where the purpose is to intentionally situate the teaching and learning of STEAM concepts and practices in either artistic or technological/engineering design (Gess, 2017). However, this could be difficult if teachers (as *adult learners*) do not experientially learn the process themselves and, while learning, become explicitly aware of *how* they are learning and how what they are learning directly *ties to classroom implementation*.

Integrative STEAM education

Literature indicates a necessary shift toward the intentional presentation of the content and practices of all STEM subjects, through the lens of “Integrative STEAM education” (I-STEAM), an inquiry-based approach that *re-designs* the course of study, in order to result meaningful learning among teachers and students who become co-inquirers in the classroom.

Shifting from the *élite* education to one “for all ages and talents”, the I-STEAM approach is anchored in the design process, an iterative process of inquiry that engineers, engineering technologists, and artists engage in to solve problems (Gess, 2015, 2017). To successfully design, the designer leverages what is known and oftentimes uses what is at hand to move through *uncertainty* and *failure*, by creating novel solutions that are retested and re-evaluated within the given constraints. However, it could be an epistemological prejudice to think that biographic interrogations are not involved in this process: as Merrill (1999) and West (1996) suggested, participation in education often has a profound effect on the self and identity by changing the lives of learners and sometimes those of their family (West 1996, Merrill, 1999). Through engagement in the design process, adult and young learners are more likely to increase in curiosity (and therefore interest), realize content relevance in their own lives, improve the likelihood for content transfer, and enhance the opportunity for significant learning to occur (Kennedy & Odell, 2014). This educational approach may be characterized by the following hallmarks:

- *Co-inquiry of adult learners and their students.* Design based learning supports not only student engagement and learning but also affords the teacher the opportunity to engage in the metacognitive and physical processes of systematic research with student subjects. Once teachers are engaged in this inquiry, they are invited to reflect on how they are “learning to learn” (meta-learning) (or *deuterolearning***,** see Bateson, 1972). Teachers may, therefore, develop themselves professionally and immediately affect data driven changes in their practice;
- *Intentional extension of learning through macro systems.* This task requires meaningful collaboration among K-12 teachers of different expertise in concert with: 1. students and their families, 2. STEAM higher education faculty and institutions (Foster et al, 2010), and 3. practitioners in STEAM industries in the immediate community and beyond (Traphagen, & Traill, 2014).

> Building such an ecosystem of STEAM partners is an essential element to building and sustaining national and international communities (Traphagen & Traill, 2014; Pitt, 2009).

To achieve this goal, educators should break down the paradigm of traditional education and commit to “learning approaches that intentionally integrate content and process of science and /or mathematics with content and process of technology and/or engineering education” and not hesitate to further integrate with other school subjects to enhance the overall teaching/learning cycle (Sanders & Wells, 2006). The integrative approach requires teachers and their students to: 1. bring together a bricolage of themes, objectives, actions, methodologies, and materials within a specific situation, in a transdisciplinary manner and 2. make connections among the disciplines, allowing them to “transfer” and apply what was learned before in new situations, and “to learn related information more quickly” (NRC, 2000, p.13).

Because learners can cross systemic boundaries to develop complex identities (Zarifis & Gravani, 2014) and because STEM/STEAM education promotes learning across the contexts, teaching “beyond the boundaries” of each discipline makes sense. In fact, while designing, thinking, and acting as designers, teachers and students engage in and realize the ways that learning necessarily converges in the real world (Lewis, 2006). Thus, in keeping with the rapidly evolving face of education, the subjects of science, technology, math, arts and engineering should be combined and presented as a *meta-discipline* (Kennedy & Odell, 2014) (μετά, “meta” is a Greek word which means “beyond” in English), existing at a higher state than each of its component parts. Therefore, another hallmark can be followed:

- *Meta presentation anchored in design.* Engaging in learning in STEM/STEAM disciplines necessitates teachers and students learning through design. Indeed, by presenting an ill-defined problem or goal that transcends all disciplines, teachers may provide an authentic context in which learners may, by engaging in the design process: 1. learn and apply content knowledge, 2. construct new curricular understandings, 3. develop habits of mind and hand necessary to succeed in a world that has yet to be imagined, and 4. develop “motivational outcomes such as ownership, agency and efficacy” (Krajick & Delen, 2017, p. 35).

The primary aim of our research was to understand the impacts of participating in an authentic STEAM challenge for the teachers and secondarily for their students. In this paper, we will show how the identities of teachers were transformed during the project, and how togetherness across boundaries of discipline and status (teacher/student) resulted.

Method

The study was qualitative and followed the narrative inquiry (Chase, 2011). Participants were eight female teachers of STEAM disciplines from a rural middle school in the southeastern region of the United States. These teachers volunteered to be a part of implementing a “STEAM education engineering challenge” presented to them by an international engineering company. As part of the challenge, their students (N = 40) were asked to participate with them. This challenge functioned as the introduction to the theory and practice of STEAM education for both adults and students, and participants were considered as a learning community. The study was approved from the Institutional Review Board of the University of the first author.

Because teachers were required to experience transdisciplinarity, the challenge was conducted in their school for three months, with the following goals: 1. designing a custom wheel for a new line of golf carts, 2. developing a marketing plan for the new wheel, and 3. presenting the wheel and marketing plan to a panel of expert engineers and marketing professionals from the sponsoring company. In order to successfully traverse the “dialectical nature of the disciplinary and interdisciplinary relationship” (Kincheloe, 2001), teachers were encouraged to look beyond the boundaries of the discipline they teach, and embrace the available tools and ideas to achieve solutions. The design process was *experience-based* (Kolb, 1984), so that teachers and students' *reflective journals* were used as a key methodological tool reflecting and describing the social, cultural and educational contexts in which the participants act, thus enabling a better understanding of the meaning of their praxis (Farrell, 2013; Hanrahan, 1999). Moreover, the journals allowed the subjects to reflect on their work processes and reconstruct their experience in relation to their roles and self-identities. As Lave & Wenger (1991) argued, learning and a sense of identity are inseparable. We followed thematic analysis (Guest & MacQueen, 2012) and triangulated the results until agreement of above 80% was achieved.

Results

Thematic analysis on the narratives revealed two main themes appropriate for this conference: 1. *Transformative learning in adult learners' professional identity*, and 2. *Learning togetherness*. We will report the voices of teachers, as revealed in the narratives, and some quotations of their students, enlightening the metamorphic process catalyzed by project participation.

1. Transformative learning in adult learners' professional identity

The first theme we are going to consider is about the crucial transformative learning that participants had in their professional identity. The transformation that we noticed in their journals beginning third week of the project shifted from being "one who was constrained" to "one who is empowered to explore". Some participants revealed being impacted by discontents associated with confusion, fear or perceived failure:

> Even though we have been given the freedom to change, we still haven't! … I'm not sure if it is fear of change or love of the status quo that keeps us from moving forward. (Teacher 7, after 4 weeks)

> I am not an art or engineering teacher. Today, I want to quit. (Teacher 8, after 1 week)

Teacher 6 seemed to struggle more than others, and yet, her participation and perseverance proved important to developing confidence, demonstrating how initial discontent may be pivotal in achieving transformation:

> I am feeling overwhelmed - confused. I don't think I can do this. I have no idea where to even begin. don't understand how this is all going to work! (Teacher 6, after 2 weeks)

> I am still out of my comfort zone. I am feeling pressured and overwhelmed. Each time I get comfortable and at ease, something else is added. I am confused and muddled again. (Teacher 6, after 5 weeks)

In keeping their reflective journals, teachers were encouraged to notice if any change occurs in their thoughts, theories, perspectives, and perceptions during the project. Participants achieved an important understanding, since they become comfortable with some issues that are crucial for adult learning (e.g. failure, uncertainty, intentional learning, wonder) (see Kolb, 1984; Knowles, Holton & Swanson, 2005; Mezirow, 2000; Zarifis & Gravani, 2014). The teachers reached an apogee of professional identity by incorporating a new frame of reference into their existing teaching schema:

> Our students need *freedom to explore*, they need to be secure in failure, and so they need ME to be secure in failure - because failure will allow us all to try new things and new ideas. (Teacher 1, after 1 week)

> Getting comfortable with *being uncomfortable* was necessary for success. (Teacher 5, at the end of the project)

> The challenges are in changing the mindset of teachers and students. I know that my class has not been this way in the past - ...projects were just fun things to do. I have to make a *conscious and intentional effort* to make this [design process] a pervasive and ongoing part of my class. (Teacher 6, after 6 weeks)

> I had never thought of these kinds of things [engineering, art problems/challenges] being a part of our curriculum. But during the process, I *surprised myself* by doing the art and engineering - and so I am not intimidated now. (Teacher 6, at the end of the project)

Additionally, we report a student's perspective to show the counterpart of this theme:

> I love this whole thing because for once in my life, I know it's okay to mess up and make mistakes. If I don't get something my team is there to help me and to explain what's going on ...Whether my thoughts and ideas are good or not, they must have *some* value to my teammates. (Student C, after 2 weeks)

An important change was specifically found in teachers' perception of why they are engaged in teaching, through biographically supported perspicuity and renewed sense of purpose:

> Today a band of teachers joined together to make learning real…. not because we are paid to WOW, not because it will increase our pay, not because of college credit, but because we want to change the face of education, we see a need for change, what we have been doing has not been working, and we have a heart for our students. (Teacher 1, after 3 week)

> Today I realize I have not been teaching for understanding, but for knowledge. (Teacher 2, after 2 weeks)

> Our administration gave us a "blank check". This did not mean money. This meant that we were allowed to make the learning decisions that we deemed best. (Teacher 4, at the end of the project)

This change seems to be contributing to a deepened value of their own professional motivation, and may consequently impact their desire to learn and teach. We also found a deep change in students' beliefs:

> Before this project, I thought the regular work in LIFE was difficult. But then [the project] came along. I learned what struggle really was. [at one] point.. I felt like I was just about to give up. But guess what. I had a new family surrounding to support me. That's one thing I've learned through this project---trust. I have learned that I need to let down my guard a little and allow someone to help me out when I'm struggling. Before this project, I believed that I could zoom through life without any help at all. But I have changed since then---I am a new person. (Student T, at the end of the project)

2. Learning togetherness

A phenomenon that teachers reported during the different stages of the project was the necessity and the benefit of collaboration and togetherness between them and their colleagues, as well as between them and their students. Participants in this project had changed their dispositions to learning as revealed in their reflection on making connections:

> I really stepped out of my comfort zone - I think we all did! The collaboration with others makes it worth it! I now know I can implement this kind of collaboration in my class. Students will appreciate learning, but more importantly, they will enjoy the process of learning; they will understand and make connections. (Teacher 2, at the end of the project)

> This week, I want to start asking my colleagues questions to make myself begin to think more, wonder more, and create more connections. (Teacher 3, after 5 weeks)

Even when uncertainty was part of the learning project, it seemed not to be a discontent for some participants; they found strength and confidence in the collective:

> I find myself questioning whether I know enough and not just in terms of content area. Do I know enough to be able to plan this kind of learning? … I know this means letting others in and relying on them and their areas of mastery. I love working with these people… *they feel like family*… but even with family, admitting not knowing something is uncomfortable. No one likes to feel dumb, but this is how my students feel. How can I ask them to take a risk and trust others if I am not willing to do the same? (Teacher 3, after 4 weeks)

> I have no idea about the outcome - but I trust my colleagues. (Teacher 3, after 5 weeks)

Teacher 4 expressed the importance of partnership with her fellow teachers in concert with external business professionals, University STEAM expert, and her students:

> Partnerships in teaching are essential. We needed the authentic problem that came from the business. We needed the authentic day-to-day contact with a STEAM education expert. We needed to rely on each other as teachers. We needed to trust our students - because they taught us as much or more than we taught them. (Teacher 4, at the end of the project)

Moreover, the process of re-design through engagement in a community of practice was an opportunity for adults to participate in, and become part of a team:

> The process was hard at times and it felt disorganized, but it came together. It took people doing things that they weren't [initially] responsible for doing because some people dropped the ball - but they did it without complaint - for the team! They did it because it needed to be done, and that makes me proud to know them! (Teacher 1, at the end of the project)

The impact of the interaction between the participants was meaningful to tie trust among them, as well as to create a more engaged relationship with their students:

> Trust in each other (fellow teachers, administration) was essential. Trust in the students was equally as important. (Teacher 5, at the end of the project)

At the same time, this transformative learning transcended isolated discipline and bounded classroom into an interconnected community, and moved participants from the "isolated person" to "we are a family", as seen not only in the teachers' voices, but also from many of their students:

> My team will stick with me no matter what. Right now we all are going through trouble and to be honest now since we have been through all this now I can call my team my *family*. My Family has helped me through it all. They have been there to pick me up when I fall down and I don't think I have had greater friends than them. (Student Z, after 7 weeks)

> Over these weeks, I have seen myself and my teammates, change drastically. I have seen my classmates grow, and become more mature. I have realized that my group and I are a good match; our brains all think differently. Since I've gotten to know my teammates, I have felt safer. (Student X, after 3 weeks)

> People will finally listen and understand. My team listens to me, adults [from the engineering team] will listen to me, everyone finally stops and says "maybe he's onto something". For once in the whole time I've been in school i feel appreciated. I don't feel like just a part of a teacher's paycheck, I feel like the people (even adults) respect and understand my mind. (Student B, after 6 weeks)

Discussion and Conclusions

The meta-discipline approach was supported by an authentic design task. The fact that the challenge in this study was presented by an engineering firm and was a *real* problem that the engineers were *actually* facing gave weight and importance to the task at hand for both teachers and students. All participants referenced this extra-curricular context as essential to the successful outcome. The existence of a design problem that transcended individual disciplines and yet required application of knowledge and understandings from each area supports the application of ISTEAM as a meta-discipline as defined earlier in this text.

The participant narratives in our study lead to the conclusion that establishing a community that can sustain itself through the constructive storm of learning is essential if the community members are to engage in knowledge creation and personal transformation through the process. By bringing together subject matter experts at all levels of education, both inside and outside of the regular school environment, who are willing to capitalize on the strengths of all participants toward a common goal, transformative learning can result for all. Indeed, this study supports assertions that for education to adequately address the needs of our students, teachers and students must participate "fully and jointly in activities where they can exercise the creative practices of imagine, investigate, construct, and reflect as unique beings committed to giving meaning to their experiences" (NCCAS, 2016, p.17).

While participating in the design challenge, all the participants in this study experienced some form of togetherness. They saw the initial experience of confusion as something that constrained them, and during the project they recognized the importance of understanding the transition between working alone and being empowered to explore beyond the limitations of the traditional educative design. All transitions, however, were accompanied by some levels of uncertainty and discontents. The experience of these difficulties are crucial cues in adult education because they reveal that the learner is going to reflect and re-frame his/her own previous understandings (Knowles, Holton & Swanson, 2005).

Pedagogically, going "beyond boundaries" requires the integration of problem framing, problem solving, collaboration and communication that cuts across disciplinary and organizational boundaries, in addition to deep disciplinary skills to meet demands for a growing society. These meta-competences emerge as future requirements across Integrative STEM/STEAM approaches (DTI, 2015). The new meta-discipline relates and integrates different epistemologies, in particular experiential knowledge about concrete real-world systems from teachers as adult learners with science knowledge about theoretical and practical issues (societal and scientific stakeholders), whereas transdisciplinarity fuses methods and concepts from different disciplines. The new meta-discipline of integrative STEAM education could improve student academic achievement in core academic subjects as a part of a well-rounded education. When correctly implemented by a "strong team of teachers with a shared vision" (USDOE, 2010, p. 16) it could also help provide "enrichment activities, which may include activities that improve mental and physical health, opportunities for experiential learning, and greater opportunities for families to actively and meaningfully engage in their children's education" (USDOE, 2010). Thus, the preparation and support of STEM/STEAM teachers should be put in place to provide a strong framework for implementation. Such training should include, at a minimum, explicit opportunities for teachers to learn together, through designing in engineering or artistic contexts, in order to build the skills and confidence needed for a meta-classroom.

Given that a qualitative study may have implicit biases, values, and judgements of the researchers, this study is subject to some limitations. First, we found an association between presenting I-STEAM as a meta-discipline and rural middle school teachers' learning of a sense of collaboration and belongingness with their students (togetherness). Further research is needed to understand if this approach can be useful in other contexts, to see if it is possible to teach this across other situations. Second, our participants were teachers (and students) of a middle-school: even if reflective journals show promising results, it would be interesting to continue with a longitudinal study, in order to understand if the effects we noted are lasting and/or if the effects correlate with student persistence in STEM fields of study. Third, this study was conducted in the United States: the replication in a European country is very welcomed, hoping to go beyond the borders and discover which best practices, experiences, and research development can contribute in the future of adult education in STEM/STEAM fields.

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