Using STEAM to Power Your Course Design

Zala Fashant

Each discipline has a unique set of thinking. There may be core elements that overlap as in a Venn diagram while there are specific thinking skills that need to be applied by novices that are preparing for a career. The STEM disciplines have defined the unique thinking and acquired skills their students require for significant learning. Recently, there has been a discussion of how the Arts are best integrated to improve STEM experiences. In this article we will examine how course design for STEM and STEAM can best meet the needs for teaching and student learning.

In our book, *Designing Effective Teaching and Significant Learning*, we analyzed the elements of integrated course design (Fink, 2013) and how today, this alignment of learning outcomes, assessments and assignments leads to deep and more engaged learning for students. This is the foundation of course design and in order to meet the goals of student retention and course completion more elements are needed to create a broader course blueprint for success.

In this article, we will apply these course design elements to STEAM disciplines using some of the additional readings we pointed to our book. If you are reading this, you are probably well-familiar with the STEM disciplines of Science, Technology, Engineering and Mathematics. Some experts will refer to the "M" as representing Medicine. The "A" in STEAM represents thinking in the Arts which some will argue is also critical for students to use in becoming better STEM graduates. Having spent time teaching in and administrating these disciplines, we would agree that components of Arts thinking is something that employers value in the workplace. We challenge you reflect on your teaching pathway from the way you were taught to your current teaching practices to being open to integrate some of the following strategies that your colleagues are finding to be successful in delivering significant learning.

> So why take time to investigate effective approaches to teaching and learning? Why make the effort to redesign a course or program that on the whole seems to be working well? A short answer comes from the experiences of many instructors around the country—successful by standard criteria—who reviewed the research on learning, reflected on their teaching, and found it wanting. Drawing on this research base, they designed ways to help their students develop a better understanding of the fundamental concepts of a science or engineering discipline, become more engaged in their own learning, and begin to think and reason as scientists and engineers do. These instructors often started with modest changes and refined their techniques over time. And their results were often encouraging (Kober, 2015, p.1).

Many of us are familiar with Eric Mazur's work at Harvard University with large auditorium course to better engage students during lectures. He discovered that his lectures didn't lead to student learning where they demonstrated mastery of the course outcomes. This is problematic since in many STEM disciplines if you don't develop a strong foundation in the early courses, you can't build the type of learning students need to have to be successful graduate, and as we discuss in our book, successful in their careers.

Designing courses and teaching where students build their own learning in a constructivist manner has been a cornerstone for many faculty to change their role in the classroom. This isn't the way most of them learned in their discipline. Rather than being *told* what to know, they would *discover* what they should know. This centers the learning on students improving their ability to truly become lifelong learners and to learn how they learn (Fink, 2013). Many faculty we have worked with observed two improvements.

The first being, more students were showing up to class. The reasons they shared was that students not only enjoyed the course content, but they liked the interaction they add with other students and their instructor. The second benefit was that there was a greater evidence of thinking and learning. Assignment and assessment scores improved. More students were achieving at the high standard.

> Completion rates are significantly lower in STEM disciplines than in other majors for all student groups and are a particular concern for students from underrepresented racial and ethnic groups, who have lower college completion rates in general (Kober, 2015, p.11).

In all learning, reflective practice is critical. As we prepare novice students to become experts and they need reflection skills to be able to achieve this. Students need to take away the ability to analyze and reflect on their work to make improvements using critical thinking as individuals or in groups.

> As novices, students approach problems in ways that are consistently and identifiably different from those used by experts. Students typically focus unduly on the superficial features of a problem, such as the specific objects, terms, and phrasing used in a question. Experts, by contrast, look at the deeper structure of the problem—the underlying principles that are required to solve it (Kober, 2015).

Students who realize that failure is a part of the learning process and have the ability to diagnose the situation and develop strategies to turn failure into success is a life skill necessary for their personal and professional lives. Employers tell us this ability to problem solve and think critically is something they are looking for in the people they hire. They don't have the time to teach them how to do this, so they want departments and programs to deliver graduates who are ready to do this.

In our book, we discuss strategies to design courses that use reflection opportunities. Fink's Taxonomy of Significant Learning (Fink, 2013) is based on domains that use reflective practices to develop STEM thinking. Faculty who understand that backward-looking assessment works for foundational knowledge and that more of the course outcomes in other domains should be designed to use forward-looking assessment will help students see themselves as the professionals they are becoming. By developing assignments and assessments where students reflect on the steps taken to learn content and the ways they tested processes and experiments will help them do in the classroom what we want them to do in the workplace.

So why you should consider changing your teaching and hence, learning for your students?

> Many of the reasons students give for switching out of a STEM major boil down to poor teaching in introductory courses (Seymour and Hewitt, 1997).

Many of you may have had a similar experience to the one I had in my high school chemistry course. The instructor sat front of the class and lectured. Then he assigned us the questions at the end of the chapter and we copied the corresponding lab procedures in our notebook while he went into the supply room and made tea, only to reenter the classroom and read the paper. We were graded on end of chapter assignments and 4 multiple choice tests for the semester. The only active part of the class was completing the labs. Meanwhile in sociology we used simulations; in band we performed on instruments daily; in health and physical education with hands-on activities, our German class used a variety of active learning experiences; and in math we interacted with the instructor and in small groups. Needless to say, I didn't take chemistry in college nor am I a chemist today.

This isn't to say that you teach this way, but if you want to reach students and develop them as experts they need to practice the foundational, research and experimental thinking to demonstrate in the classroom and laboratory. You can learn more about discipline-based education research by referring to the book in the Additional Readings at the end of this article.

> Studies clearly show that student-centered instructional strategies are more effective in improving students' conceptual understanding, knowledge retention, and attitudes about learning in a discipline than traditional lecture-based methods that do not include student participation (Kober, 2015, p.14).

"If we think about our students not being like us, not learning like us, not having the same motivations as us, then we start to imagine where they could be and we can actually reach them more easily." —Rebecca Bates, Minnesota State University, Mankato (Kober, 2015 p. 36)

The following excerpts from literature reviews, including several commissioned by the NRC to inform its DBER study, highlight the positive impacts of student-centered instruction in specific disciplines:

- In ***physics,*** results from conceptual and problem-solving tests administered to thousands of students "strongly suggest that the classroom use of [interac- tive engagement] methods can increase course effectiveness well beyond that obtained in traditional practice" (Hake, 1998, p. 1).
- Studies of ***chemistry*** education during the past decade demonstrate that various forms of socially mediated learning (in which students create meaning through interactions with others) produce positive outcomes, including "significantly higher test scores, higher final grades, better conceptual understanding, lower course withdrawal rates, and positive impacts on attitudes" (Towns and Kraft, 2011, p. 7).
- In ***engineering,*** actively engaging students "can be unquestionably confirmed as the best learning situation for learning the skills of both problem analysis and engineering design. It is also the most widely demonstrated key to deep conceptual understanding" (Svinicki, 2011, p. 15).
- Frequent assessment in combination with active student engagement has been shown to significantly improve student performance in ***biology.*** In addition, several analyses have shown that collaborative learning, particularly collaborative testing, improves student retention of content knowledge in biology (Dirks, 2011).
- To produce significant gains in learning in ***geosciences,*** "it is necessary to use instructional strategies that minimize lecture and maximize other teaching methods. We know that students learn best when they are engaged with real objects or phenomena, working in cooperative groups, solving complex problems, and interested in what they are learning" (Piburn, Kraft, and Pacheco, 2011, p. 19). (Kober, 2015, pp. 114-15.

Designing Effective Teaching and Significant Learning (chapters 2 and 5) discusses many active learning strategies to use in your course design that go beyond lecturing which include team-based learning, reflection, learning technology integration, and Process Oriented Guided Inquiry Learning.

Course design plays a critical role for minimizing barriers in STEM courses and in whole, the curriculum.

> Thus, believing that ability in STEM can improve with learning and effort is related to positive motivational responses and performance outcomes (Dai and Cromley, 2014). In fact, Dai and Cromley (2014) have shown that increases in fixed beliefs following entry into STEM courses predicted dropout in biology, beyond a student's grade. The increases in fixed beliefs were found to be associated with mes- sages conveyed in gateway courses. The authors argue that the

> structure of the curriculum and instructional strategies are associated with changes in students' mindsets, thus, leading to engagement (with decreases in fixed beliefs) or disengagement (with increases in fixed beliefs) (Malcom and Feder, 2016) .

We would argue that developing a sense of community in course design will promote the development of community within a department and campus. "Connection to community covers both a sense of belonging to an academic setting (an institution, a department, or subgroups within them) and a psychological sense of community (a broader connection to the discipline or field area)(Malcom and Feder, 2016, p. 67)."

The blending of these types of communities is what is promoted in Fink's Integrated Course Design which will go beyond the cognitive domains of foundational knowledge, application and integration and add the affective domains of human dimension of self and others, caring (valuing), and learning how to learn. Creating this community and sending positive reinforcement in foundational or early courses is key to student success, retention and provides a base for all students to see that they belong in these disciplines as a career choice. Engaging diverse students to make non-traditional career choices based on gender or race, begins with course design as it is the most direct example students will see how they can participate.

The instructional practices of faculty promoted in their STEM course design, as one would suspect, plays a major role.

> A review of discipline-based education by the National Research Council (2012) revealed similar findings: that traditional lectures are less effective then evidence- based instructional strategies at improving conceptual knowledge and attitudes about learning STEM. The report illustrated that evidence-based instructional strategies include a range of approaches, including making lectures more interactive, having students work in groups, providing formative feedback, and incorporating authentic problems and activities. In particular, the report emphasizes that instructors' clarifying and facilitating student conceptual understanding is relevant across all STEM fields. While approaches to problem solving differ across fields, most research indicates that authentic problems and appropriately sequenced experiences are important for student learning of core concepts in STEM (National Research Council, 2012) (Malcom and Feder, 2016).

More professional discipline based organizations are beginning to develop centers for teaching and learning within the discipline to share the best practices of faculty worldwide in the specific areas of STEM.

> For example, the Center for Integration of Research, Teaching, and Learning (CIRTL), which is funded by the National Science Foundation (NSF), emphasizes preparing STEM future faculty to bring their scholarship to teaching and develop learning communities for professional development at both the institutional and national levels. CIRTL has also recognized the importance of learning skills that leverage the increasing student diversity in STEM classrooms and research environments as a mechanism to enhance educational excellence (Malcom and Feder, 2016, p. 87).

Centers such as these can provide the development faculty need to better apply strategies (assignments and assessments) to provide authentic significant learning for their students. For a deeper dive, download the PDF of Barriers and Opportunities for 2-Year and 4-Year STEM Degrees listed in the references.

For a deeper examination as to how the course design information in *Designing Effective Teaching and Significant Learning* can be applied to the STEM disciplines we recommend that you read https://www.nap.edu/catalog/18687/reaching-students-what-research-says-about-effective-instruction-in-undergraduate. Many specific examples of how STEM faculty across the country have applied these changes to their courses are discussed (Kober, 2015).

Integrating the Arts into the STEM Curriculum and Course Design

More recently the concept of adding the Arts into the STEM disciplines benefits students greatly in their future work. STEM then becomes STEAM with addition of artistic thinking practices introduced. For many years, K12 education as tried to integrate curriculum ideas to form links by which students can better learn. In high schools and as students enter college the concept of discipline silos begin to develop. The advantage to this is that students have an opportunity to learn about specific disciplines in a way to choose a career field. The disadvantage is that if students decide to change majors, they may be too far down the pathway to enter a new major without starting over. One may also argue that there can be a disconnect between general education courses and those in the specific discipline. Currently there seems to be more conversations about how the courses taken during the first year or two can apply to the thinking developed within the major. In two year programs, specific courses within the general education requirements are encouraged which relate well to the work the students will do upon graduation. The value of taking a variety of courses to develop a broad thinking ability may or may not be advantage.

In our work with students and employers of our students in program or discipline advisory committees, we understand that employers are looking for specific thinking skills.

> Collaborative, critical thinking, and communication skills are valuable in an enormous range of professional domains, particularly in an era where jobs are rapidly changing. One could argue that today, more than ever, graduates need to be adaptable and lifelong learners. Memorization and long-term retention of knowledge hold less of a premium when all content knowledge is ostensibly accessible in the mobile devices in our pockets. In addition, students need to learn how to learn. They need to learn how to find information, analyze it for its validity, understand its application in different circumstances, and communicate it clearly and accurately to others. They need the critical thinking, logical reasoning, and lifelong learning attitudes required to determine whether a news headline on social media is fake and misleading or whether it offers valid and useful information upon which to base a decision. These skills and abilities will serve graduates not only in their lives as citizens and individuals but in their professional pursuits (Skorton and Bear, 2018).

This is why using the taxonomy of significant learning (Fink, 2013) (include diagram) is an advantage for students. Students gain from courses designed with the domains of foundational knowledge, application, integration, human dimension, caring and learning how to learn. These course outcomes prepare students for integration and future learning that employers expect.

> Research shows that humans construct knowledge and understanding based on previous learning and experience. Evidence from the learning sciences clearly demonstrates that moving learners from being novices to experts requires more than an increase in content knowledge. While this storehouse of knowledge is certainly necessary for building expertise, it is far from sufficient. Beyond possessing a reservoir of content knowledge, experts also have the ability to categorize and sort information, to more readily relate and connect information that novices view as disparate, and to relate that information to newly encountered content, skills, or concepts in ways

> that novices are incapable of doing. Learning new information is often easier and more rapid for experts when that information fits logical patterns that they are able to construct cognitively. Experts thus build what learning scientists refer to as conceptual frameworks, which allow them to think more deeply about relationships among pieces of information that have already been learned and to better envision how seemingly disconnected information fits with, and is related to, what is already understood. Indeed, helping nonexperts learn by encouraging and actively teaching them how to develop conceptual frameworks may also enable them to learn content more readily because they can then better understand the relevance of that information and its connections with otherwise seemingly disparate facts (Skorton and Bear, 2018).

In short, students need to be able to think in ways other than simply being experts in their disciplines. This alone doesn't suffice for students who graduate with degrees in a field where they don't enter that career and those who will need to change careers or positions within a career. Providing significant learning will prepare students to grow beyond an entry-level position. Developing thinking within students who will examine challenges and apply expert discipline, critical and innovative thinking is key to creating new discoveries and advancements within a discipline.

> History is full of examples of people who drew upon their talent and passion for science and art to drive new discoveries and advances (Root-Bernstein and Root-Bernstein, 1999). In his book *Music and the Making of Modern Science*, Peter Pesic describes how breakthroughs in physical science and mathematics were inspired through musical analogies (Pesic, 2014). For example, Kepler's Third Law emerged from his search to describe the polyphony of the planets. Faraday discovered electromagnetic induction while investigating Wheatstone's novel musical/sonic devices, Newton imposed the musical scale on colors, and Helmholtz developed alternative geometric "spaces" in response to his work on music and vision. Interestingly, history also points to examples of artists contributing to scientific and technological breakthroughs. To cite just a few examples, com- posers Leopold Mannes and Leopold Godowsky invented the Kodachrome Color Film process, sculptor Patricia Billings invented "geobond" while trying to improve plaster, and artists Heather Ackroyd and Dan Harvey revolutionized plant nutrient screening through painting (Skorton and Bear, 2018). 53

Skorton and Bear go on to identify three of most pressing challenges and opportunities facing higher education today.

- *The need to achieve more effective forms of capacity building for twenty-first‑century workers and citizens*.
- *The need to draw on the untapped potential for innovation and collaboration within and beyond the university*.
- *The need to cultivate more robust cultural and ethical commitments to empathy, inclusion, and respect for the rich diversity of human identity and experience*. (pp. 54-55)

Using the integrated course design strategies we discussed in our book, *Designing Effective Teaching and Significant Learning (Fashant, et al, 2020),* will help you meet these opportunities.

For those of you who have taken humanities course or performed in the Arts, you may already understand how this opportunity has helped your teaching within your discipline. Having been a band director let me draw a couple of comparisons for you between science and music. Let's imagine a student who is studying the saxophone and a field in science where they perform lab experiments. The goal for each is demonstrate mastery in their discipline. For each, this student uses an, or set of, instrument(s). An understanding of what is needed to create a perfect or near perfect demonstration is necessary in playing a piece of music or lab experiment. Each requires hours of studying previous knowledge and practice in preparation for current challenge. Variables play a role for the musician and the scientist. Eliminating outside variables, except the one being executed is key to getting a expected results. Analysis of performance improves future work. To say that a saxophonist and biologist then have little in common would be a mistake. The more students can understand the core thinking and practice in each they better they will perform. The saxophonist who plays out of tune may need to apply scientific principles to realize how humidity and temperature impact the quality of their performance. A lab scientist who can understand the framework of a musical composition can better perform a complicated experiment.

> The arts teach creative means of expression, understanding of different perspectives, an awareness of knowledge and emotions throughout the human experience, and the shaping and sharing of perceptions through artistic creation and practices in the expressive world. An art student's training in the methods and tools of a creative platform is complemented with studies in written and visual semiotics; critical and cultural theories and philosophies; historical antecedents that shape contemporary forms of cultural expression; and reflection-in-action through deep observation and constructive feedback.
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> The arts include not only all of these artifacts, intangible, tangible, and performative, but also the effect they have on people who participate and observe a given artistic expression. This impact has the capacity to build empathy and create new meaning for individuals in fields not limited to those traditionally associated with the arts, such as the social sciences. (Skorton and Bear, 2018).

Each of the above skills are beneficial to STEM students, so it let's examine ways that STEM faculty can integrate them into the discipline's curriculum and their course design specifically. The first way to do this, is to develop a corresponding set of recommended general education courses that will provide students with a chance to learn and practice these learning skills. This helps faculty know what most of their students are taking in preparation for discipline foundation courses. Faculty who know which courses are developing this thinking prior to their own can better design for activities that will blend prior learning to current learning. Our additional recommendation is to have faculty team with general education departments to plan together to make this experience a reality. Our experience as faculty and administration has shown how courses like these taken in an interdisciplinary approach and perhaps even team taught, can benefit students. Course can also be offered in a sequential manner so the humanities course is taken the semester before the corresponding STEM course. If course are taking simultaneously, shared assignments and activities can help students see the relationship between the disciplines. Every discipline uses design. Understanding the elements of design can help students construct their own learning in courses and in the future as they learn how to learn.

A second way to blend the Arts into STEM (STEAM) is to integrate Arts concepts into the course itself. When faculty reflect on the way their own humanities and arts education has helped the learning of their discipline they can share that with their students. By asking students to share examples by reflecting how the concepts they taken in a course previously at the institution relate with what they are currently learning. The power here is getting the students to construct their learning by linking these relationships. For instance, ask students in discussion questions how there were taught to problem solve in other courses and compare and contrast them to the ways experts in your discipline do so.

By teaming with faculty in the Arts, faculty can discuss how the integration of STEM concepts can help Arts faculty, and hence their students, benefit from this collaborative experience. Great conversations can occur when faculty from a multiple set of disciplines discuss common and uncommon teaching practices. Our recommendation is to start small. Perhaps running a pilot with one other faculty member in another discipline to get started. Team up on one or two assignments to see how it works for the two of you and your students.

For a deeper dive with specific examples faculty have teamed up to accomplish the integration of the Art into STEM to make STEAM and vice versa, read *The Integration of the Humanities and Arts with Sciences, Engineering, and Medicine in Higher Education: Branches from the Same Tree* (2018).

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Active learning increases student performance in science, engineering, and mathematics
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