TOWARDS A POST-DISCIPLINARY LIBERAL EDUCATION

Thanassis Rikakis
School of Arts, Media and Engineering (AME)
Arizona State University

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Abstract
This paper proposes that all academic fields (arts, humanities, sciences and engineering) should aim to develop a balanced distribution of disciplinary, multi-, inter- and trans- disciplinary activities. The combinations of such distributions will give rise to a post-disciplinary liberal education that can prepare problems solvers who can tackle the complex issues of the 21st century. Problem-based learning and outcome-based curricula can serve as integrative structures across the different areas of knowledge. In this context deep knowledge will take both homogeneous and heterogeneous forms. Post-disciplinary liberal education necessitates enhanced student agency, embracing of emergence by faculty and students and continuous change in curricula. It also demands new assessment structures and evaluation of individuals in the context of teams.

Introduction
President Miller put forth an exciting vision for contemporary engineering education. It is driven by societal need rather than self-referential disciplinary, academic concerns. Our society is dealing with problems that are too complex and too dynamic to be solved by limited knowledge spaces, local activities or fixed approaches [1]. These problems require distributed and dynamic solutions developed by teams of people with diverse expertise [2]. The majority of the individual members of these teams will be post-disciplinary.

Let us for now define post-disciplinary as an education that goes beyond disciplinary models while also integrating disciplinary practice (we will return to this definition later). To prepare post-disciplinary engineers that are good problem solvers there is a need to change engineering education. The new engineering education needs to be more problem driven and needs to integrate components of liberal arts education. These components will give engineers the humanistic understanding necessary for solving problems, such as sustainability, that owe much of their complexity to human behavior. Liberal arts education will also help engineers develop the necessary intellectual, emotional and communication skills for working in teams and for embracing concepts and functions of collective success. The proposed training however, cannot be accomplished by integrating traditional liberal arts education into the kind of innovative engineering curriculum described by president Miller. For example, an engineer taking a traditional music course on the history of rock music or playing in the college orchestra does not immediately become a better problem solver. In fact, mixing traditional liberal arts education with traditional engineering education may reinforce nonproductive stereotypes that treat the arts and humanities as fun, creative work and engineering as serious, dry, non-humanistic work. Such approaches hinder the transference of deep knowledge between the disciplines and undermine integrative approaches that can lead to problem solving. The training of true post-disciplinary engineers must integrate a new type of liberal arts education that is driven by the same goals as the proposed new engineering education; the need to prepare post-disciplinary problem solvers.

Developing a problem driven liberal arts education can be more challenging than innovating engineering education. Many of the core liberal art fields at the university setting see their role as primarily non-utilitarian and tied to a “push” model of knowledge. For example, some traditional arts and humanities departments focus on teaching a narrow disciplinary canon. They may teach students a whole series of great books or works of art because they believe that at some point the students will need this knowledge. This is what John Hagel and his collaborators would describe as the “push” model of knowledge [3]. The “push” model may be adequate for times of slow changing knowledge but is probably unproductive in times of fast and dynamic evolution of
knowledge. The other impediment hindering a problem driven education in arts and humanities is that these fields have not engaged utilitarian issues to the extent they are engaged by engineering. For example, the inclusion of music training in a liberal arts education is based on the notion that the practice of music makes a student a more complete human being and a better member of a balanced society. However, traditional music schools do not focus much of their energy on providing tangible evidence for this notion. This makes music and other arts units vulnerable during hard financial times where funding gravitates to efforts with solid evidence of tangible outcomes. Liberal arts units could reinforce the importance of their role in a modern university by reworking their curricula so as to directly connect a portion of their outcomes to collaborative solutions of complex societal problems. This approach will help innovate liberal arts curricula and make liberal arts units prime partners in the post-disciplinary training of STEM experts.

What I am proposing is that a contemporary liberal education requires that all fields in a university, not just engineering, change their distribution of activities. All fields (arts, humanities, sciences and engineering) need to reduce emphasis on models that primarily train students in the basic concepts of a single discipline or in the canon of a narrow field of knowledge (figure 1a). They need to develop a distribution of activities that address disciplinary training as well as multi, inter and trans disciplinary practices related to the field (figure 1b). It is understood that some disciplines like literature or music may not have as much activity in transdisciplinary problem solving as engineering but all fields need to have some baseline level of activity across the continuum from disciplinary to transdisciplinary. The combination of such distributed activity by all fields of knowledge can support the emergence of a post-disciplinary liberal education. Such education will train problem solvers with different types of expertise who can work in teams to solve complex societal problems.

I want to present four principles that can support the emergence of the proposed post-disciplinary liberal education:

- rethinking of the depth vs. breadth duality
- use of organizational structures that transcend disciplines: focusing on problem-based learning and outcome-based education
- empowering student agency (combining bottom-up and top-down approaches) and embracing emergent structures and continuous evolution
- implementing post-disciplinary assessment and evaluation structures

In the rest of the presentation, I will discuss these four principles in more detail. I will illustrate the discussion with examples from the graduate and undergraduate curricula at the School of Arts, Media and Engineering (AME) at Arizona State University (ASU), and from the operation of my own transdisciplinary research group that works on mixed reality rehabilitation systems for stroke survivors.
Overcoming Artificial Depth-Breadth Dualities

Most useful, interesting knowledge has depth. In the opening of his book “A Very Short Introduction to Mathematics” [4], Timothy Gowers discusses how the understanding of a Hilbert space requires knowledge of a whole hierarchy of lower level concepts like vector space, inner product, Cauchy sequence and convergence. Similar hierarchies of knowledge exist in the arts. For example, understanding the seminal handling of counterpoint in JS Bach’s music, requires knowledge of 16th and 18th century counterpoint, which necessitates knowledge of tonal theory, which requires knowledge of the basic concepts of music such as notes, scales, rhythms, meter etc. However, it is not necessary for an expert Bach analyst to also be an expert violinist, and an expert violinist does not need to be an expert Bach analyst. Both the master violinist and the Bach theorist share some common knowledge especially of the basics of music, but at some point their paths diverge. What is being proposed is that we can look at bodies of interdependent knowledge as tree structures. These are structures where several knowledge paths have the same root or lower level requirements. However, in a tree structure it is not necessary to know all branches of a knowledge tree to be able to handle one of its branches. Scott Page, in his book Difference [5], presents the overall idea of knowledge trees and gives a simple example: “if a person learns how to take derivatives, he can then learn how to perform integration or how to solve differential equations. Yet to solve differential equations, he need not know how to perform integration and to perform integration he need not know how to solve differential equations”. Figure 2 gives an illustration of a tree of knowledge as presented by Page. It is interesting to note that Page calls knowledge components “Tools” thus emphasizing that knowledge components and trees of knowledge are not an end into themselves but something that is used for solving real-world problems.

The idea of trees of knowledge supports the concept that deep knowledge can be achieved though a “pull” model. A student can become interested in a particular topic and learn the branch of a knowledge tree related to that topic without having to learn the whole tree. This approach can release our education structures from “push” models of learning and from overprescribed curricula that aim to have students learn most branches of all key trees in a discipline. Since the student can achieve deep learning of a branch in a discipline without having to learn the whole discipline, this also opens up time for the student to gain deep knowledge of branches across disciplines. It is of course important to make a distinction here. If someone wants to be an expert in a disciplinary area, like an expert on Bach’s music, then they will probably have to learn many branches of knowledge in that discipline. However, if someone wants to be a complex problem solver in an area like sustainability, then they need to learn the branches of knowledge that relate to the problems they are solving regardless where those branches come from in terms of disciplinary roots. Contrary to some traditional beliefs, the knowledge of the sustainability expert will be as deep as the knowledge of our music expert.

The understanding of a knowledge area branch can be improved by studying other branches of the same knowledge tree but also by studying branches of other trees. There is little comparative evidence on whether the homogeneous or heterogeneous branches approach (or a combination of those approaches) better enhances understanding of individual branches. The reason there is little comparative evidence is that most of our education focuses on covering collections of disciplinary trees rather than learning of branches across diverse trees. However, we do know that people with diverse knowledge can be excellent in certain branches of knowledge and produce highly impactful, innovative outcomes. The evolution of arts and sciences and recent literature on creativity confirm a strong connection between diverse perspectives and innovation [5, 6, 7, 8, 9]. Leonardo DaVinci and Michelangelo are obvious early examples of expertise combined with diversity. They were considered excellent painters even though they were involved in diverse activities including, in the case of Leonardo, the design of war machines. Florence Nightingale was a nurse, an author and a statistician. She
combined her diverse skills to define the basis for modern nursing and even initiate some of the ideas for evidence based medicine [10]. In a more recent example, Ianis Xenakis, who combined knowledge in engineering, architecture and music, produced significant breakthroughs in modern arts and design. His most significant contribution was the formalized use of stochastic procedures for music and visual composition [11]. The subject of open form was prevalent during his times, but the insights Xenakis produced escaped many of his highly talented, but traditionally trained contemporary colleagues.

Even though we have evidence of the connection between diverse training and innovation, in many education circles diverse training is still treated as lacking rigor. Many interdisciplinary education activities aim to provide the student with a combination of depth and breadth. This description sounds innocuous until one understands that in most cases depth is associated with exhaustive knowledge of a discipline and breadth with surface knowledge of some other areas and thus superficial. This approach excludes the possibility of deep diverse knowledge: of someone knowing deep branches of knowledge across different areas. More importantly, this approach ignores historical evidence showing that new deep knowledge can result from knowledge fusion. For example, as our world evolved with increasing speed in the past 300 years, existing areas of knowledge were combined to set the basis for new engineering disciplines (electrical engineering, computer science, bioengineering etc). These new disciplines developed rigor and depth specific to their problem sets. Of course, the single person expertise that might have been possible for earlier synthesized areas like electrical engineering is becoming much harder for new areas of fused knowledge. As the complexity of our world is increasing, we see the emergence of areas like biodesign and sustainability, where the depth and diversity of knowledge trees involved is way too large for one person to master. So each person has to pick which branches they will learn deeply, which branches they might only learn the basics for, and which branches they may not cover at all. These individuals need to then form teams that combine their individual skills into an integrated whole covering all needed areas of expertise. In this scenario, the complete deep knowledge of the new synthesized field rests with the team, not an individual. Teams covering new complex areas are necessarily diverse and thus collaboration is hard. All members of these teams need to be experts in some branches, highly skilled in integration of diverse principles, and good collaborators. We can conclude therefore, that development of new knowledge through interdisciplinary collaboration is anything but a surface venture.

Many of the artificial depth-breadth dualities we see in academia assume that knowledge is static. I therefore want to propose an model of evolving knowledge that is more fitted to contemporary reality and minimizes the need for depth-breadth discussions. The model is illustrated in figure 3. Let us imagine a circular space of knowledge. Established areas of knowledge form the defining perimeter of the circle, with each large category of knowledge (science, humanities, etc) represented by an arch. We can call the perimeter the disciplinary space. The area encompassed by the perimeter becomes the interaction space; where different branches of established knowledge interact and integrate. We can call this middle area the interdisciplinary space. Interdisciplinary interactions inform the gradual evolution of established areas but also form new areas of knowledge and related expertise. We will call these new areas transdisciplinary. As the emergent activity in transdisciplinary areas slows, these areas either get consumed into expanded notions of established areas or they become established disciplines in themselves. With older areas of fused knowledge integrating into the disciplinary horizon the interaction space opens up for new inter and transdisciplinary adventures.

![Figure 3a: established knowledge](image1.png)  
**Figure 3a:** established knowledge  

![Figure 3b: interdisciplinary interaction](image2.png)  
**Figure 3b:** interdisciplinary interaction  

![Figure 3c: transdisciplinary emergence](image3.png)  
**Figure 3c:** transdisciplinary emergence  

![Figure 3d: integration of new knowledge into established knowledge](image4.png)  
**Figure 3d:** integration of new knowledge into established knowledge
How would the training of an individual student look in this model? Let us assume for ease of discussion that each student can only learn 10 deep branches of knowledge. The distribution of those 10 branches for each type of student will be as follows. A disciplinary student will learn mostly branches from one disciplinary area, a multidisciplinary student branches from multiple disciplinary areas, and an interdisciplinary student will learn branches from multiple areas and some branches related to interdisciplinary interaction and integration. Finally a transdisciplinary student will have branches in a new area of knowledge combined with branches related to interdisciplinary integration and some disciplinary branches. All these students have an equal amount of deep knowledge but a different distribution (figure 4 gives an example visualization of the distributions). Together, these students can comprise the citizenry of post-disciplinary liberal education.

This proposed model offers students countless paths for structuring an education that fits their interests. However, there are also challenges. The model requires a modular curriculum from all participating units and a gradual abandonment of strict sequences of three-credit courses. Traditional organizational structures cannot simply be abandoned without replacements plans. New structures are needed that help faculty and students “pull” useful, coherent and meaningful liberal education experiences for the student from this open space. I propose two key meta-structures for achieving this goal: problem-based learning and outcome-based education.

**Problem-based learning and post-disciplinary liberal education**

There is strong evidence that problem-based learning promotes active learning and enhances holistic approaches to complex issues [12]. In the context of post-liberal education, structuring education and research experiences around complex problems has another very important benefit. It elevates processes and outcomes past disciplinary norms and expectations while allowing ample space for the integration of disciplinary knowledge. What I am proposing is that a student enrolling in the university should be asked to choose a set of problems rather than a disciplinary label. We should replace the traditional question of “what do you want to be?” with the question: “what kind of problems do you want to solve?” The choice of problems can be facilitated by testing for outcomes of societal significance. We should also ask: “how will solving these problems make the world a better place? How will it improve the human experience?” Focusing on outcomes of societal significance pushes the student away from toy problems and towards complex contemporary problems. When dealing with complex problems, diverse points of view and collaboration become a necessity. The participants recognize and embrace the need for post-disciplinary education and collective success. Problem based learning also invites post-disciplinary assessment approaches. Participating problem solvers don’t ask whether a solution is good engineering or good art. They consider whether the solution addresses the problem.

I want to give a concrete example of the use of a contemporary problem to organize the research and education experience of a cohort of 20 graduate students of diverse backgrounds and interests at the School of Arts, Media and Engineering. The overall problem area is improving stroke rehabilitation through the use of new technologies. Our team’s focus is developing adaptive mixed reality rehabilitation systems for stroke survivors for use at the clinical setting and the home. We consider the problem area as transdisciplinary and we involve in the description and solution of the problem not just academics but also clinical practitioners and the actual stakeholders; the stroke survivors and their caregivers. We end up with a holistic understanding of the problem but also a complex overall description that lines up well with the World Health Organization International Classification of Functioning Model [13]. In that model (figure 5) disability is connected to a network of
influences: health condition, body functions and structure, participation, personal factors and environmental factors (external influences that range from socio-economic issues to the presence of a caregiver/partner). Complicating the issue is the minimal amount of support from health insurance for long-term rehabilitation. Usually, insurance support ends six months post-stroke whereas effective rehabilitation may need 2-3 years. To give a sense of the magnitude of the problem we should mention that more than 700,000 Americans are affected by stroke each year.

**Figure 5**: The WHO Classification of Functioning model by Levin and all [13]

Our lab is developing adaptive, mixed reality rehabilitation (AMRR) systems that integrate traditional rehabilitation and motor learning theories with motion capture and sensing technologies, smart physical objects, and interactive computer graphics and sound. The systems provide real-time, intuitive, and integrated audio and visual feedback representative of goal accomplishment (e.g. did I get to the target?), activity performance (e.g. how were my reaching speed and trajectory?), and body function (e.g. did I use shoulder or torso compensation?), during a reach and grasp task. The participant (the stroke survivor) uses the feedback for self-assessment and the development of improved movement strategies. Thus the participant becomes actively engaged in her own training. The system also provides an overall quantitative evaluation of the movement and of individual movement components. The therapist can adapt the system at any time to customize the therapy to each participant’s needs and progress, as informed by the therapist’s observations and the quantitative assessment.

The following link provides an audiovisual example of the use of the system in a clinical setting (http://vimeo.com/12518365). Feedback is provided on an LCD screen and two speakers. Each reach begins with a digital image appearing on the screen, which breaks apart into many minute segments of the image, called particles. As the participant moves her hand towards a target location, the hand’s forward movement pushes the particles back to reassemble the image and simultaneously executes a musical phrase. Visual feedback communicates spatial aspects of activity level movement features (e.g. trajectory deviation stretches the image in the direction of deviation) (see figure. 6). Audio feedback communicates temporal aspects of activity components (e.g. endpoint speed controls the musical rhythm) and provides indicators for body function (e.g. shoulder compensation activates a unique sound indicator). The amount of error required to produce each type of feedback (feedback sensitivity) can be independently adjusted to fit the therapy needs of each participant. This system is currently being tested at the Rhodes Rehabilitation Institute of Banner Baywood Medical Center. We are also developing a home version of the system that stroke survivors can use for therapy in the home for as long as necessary with remote supervision by a therapist. Publications describing the systems in more detail and presenting results from studies can be found on the project website (http://ame2.asu.edu/projects/mrrehab/).

The development of this system requires expertise from many areas: medicine and rehabilitation, bioengineering, computer science, electrical engineering, visual arts and animation, music and sound design, cognitive science and psychology, sociology, industrial design and even gaming (especially for long term use at the home). The graduate students participating in this research group have a background in at least one of those areas and many of them in two (e.g. bioengineering and visual art, or computer science and music). All students have an interest in the problem area of rehabilitation overall and new media design for rehabilitation specifically. During the first year of their PhD, each new student has to spend one to two months observing sessions with stroke survivors using the system in our partner hospitals. These observation sessions are part of the research credits of the student. In their first year, students are also given ownership of designing or improving a small component of
the system so they can start participating right away in the collaborative design process. These experiences help diminish any possible narrow or disciplinary views the students may have regarding technologies for rehabilitation. The students realize that the complexities of the network of influences on disability and of cyber physical systems for rehabilitation cannot be addressed though independent approaches that focus exclusively on one component (e.g. device building or inspiring art work). As disciplinary biases fade, students are ready to participate in integrative approaches leading to generalizable principles and solutions for mediated rehabilitation.

Figure 6: Illustration of the interactive visual feedback. As the stroke survivor performs a reach, her movement pushes particles on the screen back in space to form an image.

A current inter/transdisciplinary focus of our work is the use of probabilistic networks for structuring and evaluating the relationship between training, feedback and movement learning. Within this context, media arts insights have helped improve the computational modeling processes and computational and neuroscience insights have helped improve the media composition processes. Our media arts experts use compositional methods that integrate individual feedback components into a coherent form that parallels the structure of the movement. Interactions between movement components and feedback components are categorized as explicit, implicit or extracted or combinations of those interactions. These insights on interactive form have promoted the development of computational models that go beyond one to one movement/feedback correlations found in traditional biofeedback scenarios. The computational experts of our team have developed schemes that track in parallel one to one, one to many and many to many movement/feedback correlations. The models also track propagations of direct correlations to other components and the effect of hidden nodes. All correlations also consider the effect of movement structure (movement to movement correlations). These computational schemes help all developers evaluate and improve the system and have in turn greatly influenced the media composition process. The digital media feedback sequences have become highly modular allowing any feedback scenario to be followed by almost any other scenario. The sequencing is based on the probability graphs tracking the progress of the training and the interrelationships between feedback and learning. Insights from clinicians and neuroscientists have also helped the team develop a better understanding of non-linearities in motor learning for rehabilitation [14]. This has encouraged the use of multiple time frames for the assessment and structuring of the training and the development of different feedback schemes per time frame. At small time scales, media feedback informs performance of individual movement components. Middle time-scale feedback establishes strategies for overall improvement of movement. Larger time-scale feedback takes the form of audiovisual storytelling with the evolution of the story indicating overall progress by the stroke survivor. The success of the media art forms is not judged by the aesthetic results produced by the media authors but by the engagement and learning exhibited by the stroke survivor. The team has also developed a visualization tool to help clinicians and system developers track in real time the sequence and distribution of interactive training scenarios and their relationship to changes
in the key movement components of the stroke survivor. This tool can be seen at once as a modeling tool, a composition tool or an assessment tool. More accurately it should be seen as a transdisciplinary tool for interactive mediated training.

Seeing such advancements, students in our team gain appreciation of the benefits of diverse collaboration for the team and for each individual’s work. Students develop the necessary trust and belief in interdependencies that are crucial for successful teamwork [15, 16]. Furthermore, they begin to integrate personal success with collective success. Finally, seeing the progress of the stroke survivors reassures the students of the validity and importance of their work in terms of contributions to society. The development of these beliefs and operational processes is a key part of the training of a post-disciplinary student.

Outcome-based post-disciplinary liberal education

I have presented above an example of post-disciplinary training at the graduate level. The students currently involved in such training have primarily disciplinary or multidisciplinary preparation but little experience with inter- or transdisciplinary work. Students with a truly post-disciplinary undergraduate liberal education would be much better prepared for the graduate work just described and for advanced problem solving overall. The expectation however, cannot be that students will be prepared in the exact area of their graduate research. Undergraduate liberal education programs need to be broad and cannot be constructed around narrow problems. However, grand challenge areas like sustainability, energy, biodesign or in the case of my own work, digital culture, can act as reference frameworks for structuring broad, undergraduate post-disciplinary liberal education programs. An outcomes based approach should be taken in organizing such programs. The different areas of knowledge that can contribute to a grand challenge should collaborate to develop a common list of proficiencies that students interested in this challenge should possess. Then, course-work and research projects should be developed by all partners using these proficiencies as prerequisites and outcomes.

We recently used this approach at ASU to structure a post-disciplinary curriculum on digital culture (http://herbergerinstitute.asu.edu/degrees/digital_culture). The broad goal of the curriculum is to study how new media can improve the way we live, learn, create and communicate. Representatives from fifteen disciplines spanning arts, design, engineering, education and the social and behavioral sciences got together and developed a list of 25 digital culture proficiencies such as form and composition, modeling and inference, social mechanisms and understanding, and improvisation and rapid prototyping. All 25 proficiencies can be used at the 100, 200, 300 or 400 levels. Forty courses, covering levels from 100 to 400, have been developed by the participating units. Each course has different combinations of three to four digital culture proficiencies as its prerequisites and outcomes. The courses are organized in six large categories: core digital culture, media arts, media engineering, general digital culture, historical/theoretical, collaborative projects/capstone experience. Two more categories of courses complete the degree map: general studies and disciplinary core. Students are given a number of credits per category necessary for completing a degree. Depending on the degree (BA, BS etc), the amount of credits per category varies and so does the disciplinary core (students can do their disciplinary core in arts, design or engineering). Because all digital culture courses are interconnected by the common proficiencies, students have numerous choices of paths for completing the required digital culture hours and for constructing their preferred networks of proficiencies.

When developing individual courses for such a curriculum, faculty should adhere to the basic principles outlined in this talk. Courses should integrate collaborative problem solving. Coursework must be modular. Courses should cover branches of knowledge without expectation that students know all related branches of a tree or all related disciplinary trees. Subjects should be approached from a broad perspective thus allowing students with different preparations to attend each course. Faculty should not focus only on proficiencies familiar to their discipline but should develop courses that reveal useful correspondences between the diverse proficiencies of a grand challenge area. Let me expand on this last idea, as it is critical.

We discussed earlier how a mediated rehabilitation project can leverage interactions between modeling and inference (which may be considered primarily an engineering proficiency) and form and composition (which may
be considered primarily an arts or design proficiency). I want to now use a research project by Keith Sawyer [17] to show how a theater improvisation project can allow a course to cover four diverse digital culture proficiencies. Sawyer asked two groups of professional actors (groups A and B) to create two improvised plays. Actors in group A were allowed to step out of character and use “director talk” to make decisions about the structure of the play. In group B however, all metapragmatic negotiations about the structure of the play had to be accomplished while speaking in character. In his analysis Sawyer found that the play developed by group A had a complex plot with interwoven subplots but weak character development and relationships. In contrast, the play of group B had a simple plot but emphasized character and relationship development.

Running this project in class and approaching it in parallel as a form and composition, modeling and inference, social mechanisms and understanding, and improvisation and rapid prototyping problem, can produce deep insights about the project and its process, elevate the student’s understanding of these four proficiencies and illuminate connections and interactions between different areas of knowledge. Digital capture and analysis of some of the project parameters can also be added. The captured parameters can range from simple ones, like time of participation of a character or time of interaction of two characters, to more complex ones (searching for keywords or analyzing intonation and rhythm of the dialogues). Display of results to actors in real-time and off-line can produce further insights on all aspects of the project while also investigating the role and effect of digital technology in complex human activities.

**Empowering student agency and embracing emergent structures**

Although the high level structures of a post-disciplinary curriculum need to be prepared by the faculty, the curriculum must encourage student agency and participation. Students should be able to develop their own education paths within the high level structures put in place by the faculty. Direct student input and patterns of student activity should be considered in the assessment and evolution of the curriculum.

I want to discuss four tools we are putting in place to help student’s participate in the structuring of their education in digital culture. The first tool allows students to explore different paths for completing their digital culture degree. The student logs into the system and creates a path name. She then begins to explore courses and paths between courses. Let us run a quick example. While exploring, the student becomes interested in the 200 level course “Hybrid Action: Physical Intelligence in Digital Culture” offered by the School of Dance. She sees that she cannot add the course to her path because she is missing the proficiencies of Collaborative Principles and Essay Writing. She chooses each missing proficiency and the map reorganizes to show which 100 level courses offer them. She chooses an AME course and an English course to get these two proficiencies. The courses get added to the fall and spring semesters of her first year. She can then add the Dance course in the fall semester of her second year. She follows a similar process to add a computer science visualization course for her junior year (the course requires proficiencies she can get by signing up for an animation course offered by the School of Theater and Film in her sophomore year). The student can continue to add more steps (courses) to this path, create and compare different variations of the path or just explore new paths. This tool, developed by Loren Olson, is already online and being used by our students.

We are in the process of developing three more tools to help students, faculty and advisors structure each student’s experience. The first tool takes each path developed by a student and matches it to the formal degree map. The student and advisor can use this tool to monitor degree completion and adjust the student’s preferred paths to better meet degree requirements. The second tool extracts networks of proficiencies for each path. It shows the proficiencies each path will provide and the volume of each of the proficiencies in the network (how many times the student will have covered each proficiency through their selected courses). We plan to track student placement and to work with human resource offices in key digital culture related companies to establish correspondences between networks of proficiencies completed by students and hiring patterns in industry.

Through this process we also want to display to students that there are many different paths to each type of career. We are also hoping that our curriculum can produce students and groups of students that will start their own companies and trends in digital culture. We plan to use our tools to extract networks of proficiencies that support entrepreneurial behaviors. Finally, our third tool is a social networking tool for digital culture. For each course
on our map we plan to have recommendations by faculty and students regarding other courses that connect well to that course both in terms of preparatory steps for the course and consequent steps after the course is competed. We will also have automated recommendations (i.e. “other student’s who took this course also took these courses”). Through this tool students will be able to compare their paths to paths of other students who are willing to share their data. There will also be an online media exhibition space where students can share projects they created in different courses.

Such tools can encourage student agency, facilitate customization of education to each student’s interests and provide useful data for assessment and evolution of curricula. In the context of our digital culture curriculum, we will use these tools to search for simple trends (popular courses, popular paths etc.) as well as complex ones (which courses cover particular proficiencies well, which courses produce most unexpected and entrepreneurial outcomes etc.) and use the results for continuous improvement. The fast evolution of contemporary grand challenge areas and the active engagement of students in the structuring of their education will promote emergent structures and continuous change. Contemporary liberal education must evolve continuously in order to remain consequential.

Post-disciplinary assessment and evaluation structures
Assessment structures for a post-disciplinary liberal education curriculum must be in keeping with the key design principles of such a curriculum [2, 18]. The focus should be on whether the curriculum is training problem solvers and whether these problem solvers are having an impact on society. We have not yet implemented our planned assessment structures for digital culture so I will not discuss these in detail. However, we have implemented some significant changes in the way we evaluate faculty at the School of Arts, Media and Engineering so as to encourage inter/transdisciplinary processes and outcomes. I discuss our evaluation and promotion and tenure criteria in detail in a recent publication [19]. In closing this talk I want to briefly highlight three elements from these criteria that I believe can scale well to the evaluation of students, faculty and learning outcomes of post-disciplinary liberal education.

i) Calibrating evaluation matrices across a diverse set of outcomes and practices
Post-disciplinary work in grand challenge areas produces a broad range of outcomes. To facilitate evaluation, it is important to develop a meta-matrix that can help calibrate assessment of different outcomes in a quantifiable manner. For example, work at AME bridges engineering, sciences and the arts. Outcomes range from high impact journal publications, to software and hardware systems, fieldwork in schools and communities, and performances. To promote a calibrated evaluation of projects, and of faculty and students working on the projects, we produced a hierarchy of four outcome categories: major, standard, minor and supportive. All participating disciplines were asked to provide some form of quantitative criteria for ranking all possible research and creative activity outcomes of their discipline into these categories. These criteria were then combined into unified guidelines for classification of all AME outcomes. The creation of this meta-disciplinary measurement system allows AME to set expectations in terms of numbers of outcomes per category per evaluation time frame. For example: a well-supported research team at AME is expected to produce at least 2 major and 2 standard outcomes per year. Each of the four outcomes however can be very different. Evaluators not familiar with a particular type of outcome (i.e. an engineering faculty member might not be familiar with the impact of an installation at the Exploratorium in San Francisco) can develop an appreciation of the significance of that outcome through its meta-ranking as major, standard or minor. An evaluator not familiar with the area of activity of an AME faculty member (i.e. a psychology faculty may not be familiar with media engineering journals and conferences) can still approach the record of that faculty member in terms of the number of major or standard products he has produced and compare that record to the records of other AME faculty.

ii) Expanding the notion of “gatekeeper” and “impact”
Post-disciplinary work that aims to solve real-world grand challenges cannot be evaluated solely by academic criteria or academic experts. Furthermore, assessment should not solely focus on seminal pieces of standalone work. Insights from real world stakeholders and measuring of impact in terms of improving daily life must be integrated in the evaluation process. For example, the AME criteria allow for an embedded media system or
methodology to be treated as a research outcome in its own right and be categorized as a major, standard or minor research product based on two indicative embeddedness criteria: a) the level of product adoption by the relevant communities (i.e. how many teachers in K-12 schools use the system to deliver curriculum; how many students are taught) and b) the level of documented improvement in daily life of relevant subject groups (i.e. a considerable number of stroke survivors are using the system to enhance their daily rehabilitation routine). Similarly, a very popular blog that enhances societal reflection on sustainability could also be considered a major or standard product.

iii) Rethinking authoring conventions.
Team authorship in post-disciplinary work cannot always be handled through traditional authoring conventions. Therefore AME criteria include two approaches to listing authors. If the contributions of the main authors are clearly gradated, then traditional author listing must be used (1st author, 2nd author etc). If the contributions of main authors are of equal effort and significance, then group authoring must be used. In group authoring, all lead authors are listed as primary authors and the remaining authors as either secondary or contributing authors.

iv) Integrating individual and team evaluation processes
Post-disciplinary experts need to be good individual members of successful teams. Being weak members of good teams, or great individual members of unsuccessful teams, or just great individuals that cannot work in teams is not adequate. The evaluation of post-disciplinary students and faculty necessitates methods that assess an individual in the context of a team. For example, the AME criteria assign 20% of the weight of a faculty or student evaluation to interdisciplinary connectivity: the ability of a member of AME to successfully collaborate with their colleagues and bridge different perspectives. We can measure the strength of the connection between any two members of the AME community based on the number of collaborative research outcomes these two members have jointly worked on. We can measure each member’s network in terms of size (number of connections), strength of connections, repeat and new connections and interdisciplinary make-up of connections. We can also review the number of authors per research product and the number of disciplines per research product of a member.

Using all above strategies it is possible to perform a post-disciplinary evaluation of a team or individual. How many major or standard products as a primary author does an individual have? How diverse are those outcomes? How many of the outcomes of a research team are strongly embedded in the real world and adopted by practitioners? How strong, inclusive and balanced is the network of a team?

Conclusion
Post-disciplinary liberal education is a highly fitted preparation for the complex world of the 21st century. It is also a very exciting challenge for the academic community. I appreciate the opportunity to participate in this workshop on engineering and liberal education and be able to share thoughts and insights with so many distinguished colleagues active in this area. Thank you for your time.

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