Transdisciplinary and Trans-sector Knowledge Ecosystems Leverage Interdependencies, Promote Agency and Advance Knowledge Democracies

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Abstract
The paper predicts significant future expansion and differentiation in knowledge production and management practices across seven dimensions: novelty, connectivity, continuity, customization, access, unit of production, and discourse composition. Knowledge practitioners who leverage the interdependencies of highly differentiated experiences across these seven dimensions can support the development of knowledge democracies producing outcomes that are highly impactful but currently unrealized. We analyze challenges faced by cross-disciplinary discourse in United States academia to propose that the higher education sector in its current instantiation cannot independently foresee or ultimately support the full scope of such a knowledge democracy. Quintuple Helix transdisciplinary knowledge ecosystems integrating industry, academia, government, civil society and socio-ecological environments may be better positioned to explore the pluralistic knowledge needs of 21st century society. The richness, openness, and interdependencies of these ecosystems can enhance creativity, increase the agency of knowledge practitioners, promote multi-perspective reflective practice and advance socioeconomic sustainability. At the same time, the complexity of Quintuple Helix experiments may hinder the full-scale achievement of these aspirations. However, our underlying contention is that these experiments should result in groundbreaking perspectives driving further experimentation.

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1. Introduction and Motivation

The rapid and significant socioeconomic changes of the 21st century are affecting all major structures and institutions of our society, including academia. Recent public surveys (Brown, 2018; Jones, 2018) indicate that American higher education is not handling the ongoing disruption successfully and may even be heading in the wrong direction. Key reasons for the negative public opinions about higher education include rising costs, access policies that are not inclusive and inadequately address rising demand, and mismatch between learning outcomes produced by higher education and the skills demanded by employers (Banerji, 2007; Hart, 2016) and required by our complex societal needs (Madrigal, 2017). In this paper, we argue that these issues cannot be addressed individually through change-in-management structures or a series of one-off, piecemeal solutions, such as market driven budgeting. Universities are above all else institutions designed for the express purpose of creating and disseminating knowledge. Therefore, we believe that in order to address the perceived mismatch between academic practices and societal needs, we need first to explore a key question: what are the emerging and future knowledge needs of 21st century society?

The growing global knowledge economy is continuously increasing and diversifying the number of people that are involved in knowledge discovery, dissemination and application (Lucas, 2012; Morrar, 2017) The reasons for, and ways in which people engage in knowledge production and management are also rapidly diversifying (Meige, 2015). This continuous growth and diversification will result in a significant expansion of knowledge practices along several dimensions. The expansion may be thought of as a simple random walk process along each dimension the outcomes of which at any step are binomial. The outcomes of a large number of such steps taken can, under fairly general conditions, be shown to be approximately Gaussian as a result of the Central Limit Theorem (Hermans, 2013). Although knowledge features used on each dimension will span a broad scope, over time the overall distribution of feature usage will behave in a manner consistent with a normal distribution, with a larger number of experienced features accumulating near the center (Gnedenko, 1954). For the purposes of this paper, we focus on seven key predicted dimensions that we believe will dominate discussions on 21st century changes in knowledge production and management.

1. **Novelty**: The fast pace of technology and socioeconomic innovation (Morrar, 2017) will consistently add new knowledge and evolve existing knowledge (Adler, 2015), resulting in a normal distribution of knowledge practices extending from established and static practices to emergent and rapidly changing practices (S. S. R. Council, 2018; Hagel, 2014).
2. **Connectivity**: the increase in global connectivity will decrease the percentage of knowledge that is siloed or isolated (Castells, 2009), and will normally distribute knowledge over a continuum extending from compartmentalized knowledge to fully connected knowledge (Katz, 2014; Lucas, 2012).
3. **Continuity**: The rate of change and interconnected complexity of knowledge will result in a normal distribution of impactful knowledge discovery extending from well-established paradigms of smoothly continuous discovery (discovery well connected to the canon and gradual) to discontinuous and disruptive discovery (Cohen, 2001; Mukherjee, 2015; Rooney, 2005; Schilling, 2011).

4. **Customization**: The rise of asynchronous knowledge delivery, smart tutors, and learning analytics (Koedinger, 2014) along with the growing realization of the effectiveness of individualized tutoring (Selingo, 2019) will distribute knowledge dissemination practices on a continuum extending from fully standardized paradigms (that dominated the previous century) to fully adaptive (Davidson, 2017; Murray, 2015; Senge, 2000).
5. **Access**: Social imperatives and the fast growth of the knowledge economy will increase and diversify access to knowledge production and management (Education, 2016; Greenstein, 2017). Access will extend from restricted or filtered to unrestricted, with the majority of practices being varied combinations in the middle of this continuum (Altbach, 2007; Crow, 2015; Education, 2016; Greenstein, 2017).
6. **Unit of production**: The growing realization on the importance of teams in tackling complexity (Fam, 2018; Page, 2007), coupled with the understanding of the challenges of team work (Mannix, 2005) and the importance of individual agency and creativity (Csikszentmihalyi, 1990) will create a normally distributed continuum of knowledge production units extending from individuals to large teams (Kania, 2011; Leahey, 2017; Uzzi, 2013).
7. **Discourse composition**: Discourse that spans knowledge areas (e.g. sciences and arts) (Darbellay, 2015; Page, 2007), knowledge sectors (e.g. academia and industry) (Katz, 2014) and knowledge domains (e.g. cognitive, psychomotor, affective) (Anderson & Bloom, 2001; Hutchins, 1995) is correlated with innovation and social sustainability. At the same time homogeneous cohorts can be more effective in advancing specialization (Abbott, 2001; Mannix, 2005). These realizations are maturing in parallel and will redistribute knowledge discourse on a continuum spanning fully homogeneous to fully heterogeneous (De Weck, 2011; Fazey, 2014; Klein, 2015; Tegarden, 2009).

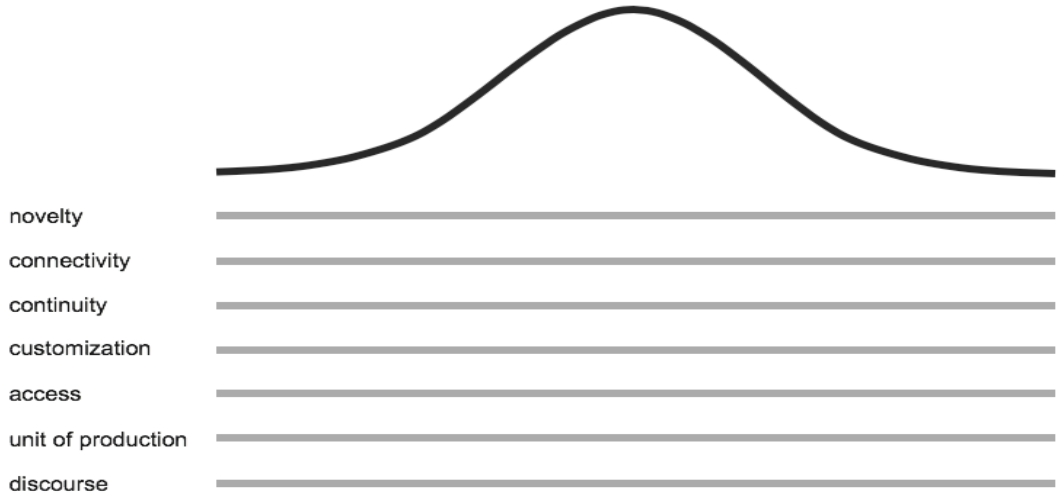

Figure 1; seven dimensions of knowledge change in the 21st century

Figure 1 places a normal distribution over these seven predicted dimensions. It is important to note that even though we present these dimensions separately to facilitate discussion, the dimensions are of course interacting (Davis, 2006; Watts, 2003). We propose that as the heterogeneity, connectivity, and discontinuity increase from left to right so does the entropy (Watts, 2003). Therefore, a meta dimension that can characterize these interactions is knowledge entropy, extending from predictable and controllable to unpredictable and hard to manage. Using the Perez model of cycles of

major socioeconomic change, we suggest that every 40 years smaller changes will accumulate into more significant shifts in knowledge production and management (Perez, 2002). Some novel elements from the previous period will become more established (thus shifting to the left in our representation), some established ones will fade away, and some previously unknown elements will be introduced. For example, computer science as a knowledge area was a novel element in the 1970s but is now an area that combines both new and established knowledge. However, some current predictions propose that the Perez model will be replaced by constant innovation, in which case the time bracket for re-averaging elements will be shorter than 40 years (Adler, 2015). Regardless of the exact pace of innovation in the 21st century, we can be fairly certain that knowledge practices will change significantly from the time an individual enters the knowledge economy as a trainee, to the time they retire. Life-long learning, embracing of unpredictable career paths, and dynamic knowledge production and management platforms (Swearer, 2015) will be essential components of 21st century knowledge ecosystems.

Knowledge is well understood to be embodied, experiential and contextual (Dourish, 2001; Hollan, 2000). Although the overall average of knowledge experiences within the 21st century knowledge economy may approximate a normal distribution, individual experiences may show different average distributions or utilize customized permutations of elements across the seven dimensions (Cohen, 2001). For example, a heterogeneous team experience could be combined with restricted access and moderate connectivity, while an individual experience could be highly adaptive. A knowledge ecosystem with a large number of available experiences that are customizable based on context will be inclusive to people and practices (Hagel, 2014) . Differentiated individual participants that are sensitive to the interdependence of varied individual experiences within a complex ecosystem (Hutchins, 1995) and have agency to creatively explore and expand the ecosystem (Sawyer, 2007) can develop 21st century knowledge democracies (Carayannis, 2014) that combine a rich common core of knowledge attributes with expansive arrays of differentiated features. Or put differently, a knowledge ecosystem that exhibits the Gaussian distribution properties described in this introduction. Since the integral combinations of common and differentiated features will be embodied by the individual members of these democracies, these ecosystems can support high network density across both homogeneous and heterogeneous practices which can be transformational in terms of knowledge organization and socioeconomic outcomes (Eagle, 2010; Grabher, 1997; Reagans, 2001).

The realization of such pluralistic systems is challenging. It may necessitate that knowledge communities combine existing knowledge practices with more novel ones that can promote an inclusive statistical comprehension of individual and complex societal knowledge. For example, Ianis Xenakis tried to model this problem in sound (Xenakis, 1971). He composed music using stochastic processes that promoted a shift from deterministic to statistical interpretations of complex experiences. He proposed that this shift facilitated the appreciation of the full spectrum of available features on each dimension of an experience and the perception of each dimension as a continuum with the edges of the continuum (i.e. order to entropy) being only two of the many available instances. This type of statistical interpretation (Gallistel, 2014; Vul, 2009) avoids hierarchization between available instances of an experience

continuum (i.e. ordered instances are not better than less ordered ones) and opens limitless possibilities of combinations of features across dimensions.

Similarly, Chatterjee suggests that experiential learning that embraces inclusive exposure to the full dimensionality and complexity of societal challenges such as human rights (Chatterjee, 2019; Consortium, 2019) results in impartially-partial knowledge practitioners who embody the philosophical concept of the View from Nowhere (Nagel, 1986). These knowledge practitioners are passionate (partial) about their experiences and points of view but also impartial in that they are aware of the wide spectrum of possible experiences, the limitations of individual points of view, and the richness that results from the co-existence of different experiences. These practitioners can form global democracies where traditional polarities (such as statism and globalism) can coexist within individual members as synergistic points of view (Chaterjee, 2009). The Chatterjee concepts can be seen as one characteristic instance of a greater category of transdisciplinary and trans-sector knowledge practices that are based on deconstructionist philosophy (Darbellay, 2015; Osborne, 2015). These practices aim to promote acceptance of multiple realities by members of a knowledge ecosystem (Nicolescu, 2002). Such collective acceptance advances multi-perspective reflective practice which in turn has the ability to produce new types of transformative solutions to 21st century problems. Already, cross-field and cross-sector transdisciplinary methodologies integrating an expanded and inclusive approach to expertise are gaining prominence in exploring complex problems such as sustainability (Carayannis, 2013; Evans, 2015; Vincent, 2015).

In the following sections we aim to address the following question: Is the current higher education sector able to support a pluralistic exploration of the expanding knowledge production and management space and generate knowledge democracies that advance a 21st century sustainable and inclusive society? We focus our interrogation of this question primarily on the socioeconomic context of American higher education, but we believe that many of the concepts discussed may also apply more globally. During our exploration we use the term transdisciplinarity to denote an inclusive discourse process that transcends disciplines and sectors (i.e. industry, academia) (Klein, 2015) and aims to shape reflective practitioners that leverage multiple perspectives (Darbellay, 2015). We use the term interdisciplinarity to denote a process that integrates insights from two or more academic disciplines "to solve problems whose solutions are beyond the scope of a single discipline" (Sciences, 2005), (Klein, 2015).

2. Great Universities as Anchors of Transdisciplinary and Trans-sector Knowledge Ecosystems

2.1 The current set up of higher education and 21st century knowledge needs

The disciplinary department based structure that remains dominant in American higher education was optimized to support knowledge practices relevant to the society that emerged from the second industrial revolution (Crow, 2015; Davidson, 2017; Senge, 2000). This educational structure fulfilled, and continues to fulfil, its knowledge goals very successfully. The concept of the "Great American University" has been a key factor in the growth and development of the United States in the 20th century (Cole, 2009). However, this educational structure primarily supports the left part of the distribution of 21st century knowledge presented in our introduction.

Disciplinary education focuses on the efficient and reliable production of standardized knowledge at scale (Buanes, 2009). The disciplines achieve this efficiency and reliability by maintaining homogeneity of knowledge practice (e.g. participants specializing in the same areas of knowledge and using similar methodologies) and avoiding radical discontinuities (e.g. insights that don't have a direct or linear connection to the existing disciplinary canon) (Krishnan, 2009; Menand, 2010). Furthermore, the disciplines stay focused so as to allow for individual disciplinary expertise; one person being able to keep up with the full scope of the discipline (Abbott, 2001). The disciplines rely on strong gatekeeping mechanisms (standardized testing, accreditation, consistent peer review) to maintain the desired homogeneity, continuity and focused perspectives (Abbott, 2001; Jacobs, 2013). Fixed disciplinary curricula assume that universities educate students for a sole known purpose that remains fixed for the significant duration of a person's professional career (De Weck, 2011). Knowledge dissemination that is standardized and has fixed goals tends to promotes restricted access (Crow, 2015). The mechanistic origin of the current system also emphasizes determinism and hierarchization in knowledge outcomes. It is assumed that there is one best solution to any problem and that it can be found by breaking a problem into specialized components. These components will naturally come together in the one and only way allowed by that solution (Senge, 2000).

The increasingly partial coverage of 21st century knowledge needs by the existing university structure is well documented over the past ten years (Banerji, 2007; Engineering, 2005; Flowers, 2009), and indeed first predicted over thirty years ago (d'Hainaut, 1986; Jantsch, 1972). These initial predictions served to motivate the significant growth of interdisciplinarity, aimed at embedding more collaborative and heterogeneous innovation processes across the academic enterprise to gradually create a more dynamic university, better fitted to the more unpredictable parts of 21st knowledge (Knight, 2013; Sa, 2008; Sciences, 2005). After twenty-five years of working on this integration, the academic enterprise shows a growing list of successes that range from mildly continuous to moderately discontinuous in their relation to previous knowledge and are developed by small teams that balance homogeneous and heterogeneous perspectives (Donovan, 2015; Magnusson, 2018; Uzzi, 2013). These impactful outcomes are in great demand by our society (S. S. R. Council, 2018; Hart, 2016; Madrigal, 2017) but still form a minority, rather than the central peak, of the distribution of current academic knowledge production (Leahey, 2017; Mukherjee, 2015; Schilling, 2011).

A more detailed look at the growth of interdisciplinary education in US academia provides some of the reasons for which interdisciplinary education has not been able to create a bigger shift in overall academic practices and outcomes. The implementation of many interdisciplinary initiatives rely on some variant of a matrix structure, with interdisciplinarity represented on the horizontal axis and disciplinarity on the vertical axis (Sa, 2008; Sciences, 2005). The vertical is usually served by disciplinary departments and the horizontal by thematic faculty clusters, research centers/institutes or education programs (or some combination of the three) that bring together faculty and students from different disciplines. This structure (also known as the T-shaped model) illustrates the productive coexistence of interdisciplinary and disciplinary knowledge practices and is key in helping interdisciplinarity grow (Sciences, 2005). However, it also serves to frustrate the evolution of the university towards 21st century knowledge needs as the model treats interdisciplinary and

disciplinary knowledge as different dimensions rather than variants of the homogeneous to heterogeneous knowledge continuum. The opportunity to train a large number of practitioners that embody various combinations of disciplinary and interdisciplinary knowledge is thus missed. Furthermore, in the T-shaped model the depth is assigned to the discipline and hybrid knowledge is treated as breadth which formalizes an artificial hierarchy where disciplinarity is by default "the" core knowledge; "the" point of view against which any new knowledge structures need to be assessed.

A recurring point of frustration for faculty and students participating in interdisciplinary work in American universities is that the disciplinary departments do not uniformly support or incorporate the knowledge practices that emerge from interdisciplinary activity because they are found to be too applied or too distant from the disciplinary core (Hein, 2018; McLeish, 2016; Pfirman, 2011; Samuels, 2015; Stern, 2010). Faculty members describe being advised by disciplinary colleagues that new insights belong to the knowledge space of the interdisciplinary program, rather than the discipline. They are further advised to stage their involvement; first achieve solid status and tenure within the discipline before engaging in "distant" interdisciplinary activities.

The philosophical resistance of the disciplines towards interdisciplinarity is strengthened by organizational or bureaucratic structures (Abbott, 2001; Menand, 2010). In the American university model of the last two centuries, the disciplinary department is at once the fundamental unit of knowledge organization and of operations. It controls the key features of the university: hiring, promotion and tenure, structuring of the educational majors, university funding based on enrollment, and gatekeeping of research. This gatekeeping of research goes beyond any particular university as universities have similar departmental structures which guarantees that disciplinary peer review globally has similar expectations (McLeish, 2016). The traditional academic department is the only context in which one can pursue a stable and focused area of investigation throughout a 40-year professional career (Abbott, 2001). The structure of disciplinary promotion and tenure is a powerful binary moment (you either get a job for life or you are fired) and there is scant adaptation. Tenure track faculty must seek promotion after six years, even though it is well understood that some fields (for example those requiring the collection of complex data in the wild or broad collaborations) may have higher transaction costs and may require more time to demonstrate results (Samuels, 2015).

Many US interdisciplinary initiatives try to solve the problem of the discipline resistance by giving independent status to successful interdisciplinary programs and centers. These units have a permanent budget from the university, the ability to host partial faculty lines or even give tenure to faculty in the program using interdisciplinary criteria, and they can offer new interdisciplinary majors (Brint, 2005; Crow, 2015; Knight, 2013; Sa, 2008). However, this approach further separates interdisciplinary programs or institutes from the disciplinary programs they are expected to synergize and collaborate with and in some cases places the interdisciplinary programs in competition with their related disciplines in terms of people, resources, and knowledge practices (Sa, 2008; Stern, 2010). This approach also makes it hard to sunset interdisciplinary units when the problem space they are

organized around changes or it subsumed by newer problem spaces or grand challenges (Hartesveldt, 2008; Popowitz, 2018).

The growth of interdisciplinarity in parallel with the disciplines, with limited effect on innovating the disciplines themselves, does not meet the original motivations for the growth of cross-disciplinary discourse (Klein, 2008, 2015). Such discourse was supposed to create new insights to be incorporated into the disciplines and in the process continuously change the disciplines (d'Hainaut, 1986; Derrida, 2004; Foucault, 1969, 1971). This process of contextualization, de-contextualization, and recontextualization would continuously deconstruct knowledge production and management, allowing it to keep pace with the needs of a fast-evolving society (Osborne, 2015). The coexistence of the established and the new would support knowledge practitioners that can embody multiple perspectives (i.e. disciplinarity, inter and transdisciplinarity) and are comfortable moving between different levels of order and entropy (Darbellay, 2015). For example, the stochastic music of Ianis Xenakis, John Cage and other pioneers in the second part of the 20th century placed probabilistic events, like the song of crickets at night, on the same order to entropy continuum as deterministic music (like rhythmic and tonal songs). The resulting expansive conceptual space allowed artists and scientists to work together in an open-ended manner that leveraged the growth of media computation and the creativity that emerged from the collision of different ideas. Their work promoted the emergence of the meta-concept of music as organized sound that could have applications everywhere (from concerts halls, to education, health, information and communications) and was modular, mobile and accessible to everyone as a listening and making experience (Roads, 2015). However, much of this work happened in new cross-discipline and cross-sector centers and programs rather than through expansions of traditional music programs, which in many cases remained skeptical about the musical value of this revolution (Makch, 2015; Wisnioski, 2013). Many traditional classical musicians who opposed Xenakis approach to music maintained that when people have a choice, they will choose to listen to deterministic and ordered classical music over the chaotic noise of statistical composition. Xenakis counter proposed that people are equally happy to listen to the stochastic sounds of crickets, wind in the forest, and sea waves as they are to listen to Mozart or Debussy. When all these experiences are accepted as a continuum of organized sound, then new music possibilities open up, such as the revolution of digital sound described above (Xenakis, 1971).

We similarly propose that a dramatic expansion of organized knowledge production and management supporting radically different but interconnected experiences that combine features across the full spectrum of key dimensions of 21st century knowledge (see Fig 1) could result in an inclusive global knowledge democracy that generates socioeconomic outcomes that are highly impactful but currently unimaginable. However, individuals or institutions that limit their experiences to one part of the possible spectrum of 21st century knowledge practices, or create hard-wired separations between different parts of the spectrum, will be challenged to imagine and eventually support the full scope of such a knowledge democracy. After a while, their limited experience becomes "the" point of view and constrains their imagination. The uneven effect of interdisciplinarity on American higher education because of the optimization of higher education towards the more ordered (deterministic) part of knowledge production is a clear illustration of this problem.

At the same time, some key transformative initiatives in American academia in the past 20 years crossing knowledge sectors (industry, government, community and academia) have created collective experiences that leverage the full spectrum of some of the proposed knowledge dimensions of our 21st century knowledge model. In the process, these initiatives have provided impactful recontextualization of traditional academic practices. The commitment of American universities such as Arizona State, Georgia State, and the University of Maryland at Baltimore County to advance in tandem with their surrounding communities in an inclusive manner brought into the conversation community experts (from K-12 and community college teachers to local government and community organizations representatives) who had significant experience with increased heterogeneity and adaptation. A new concept of access and excellence was created, where excellence was not associated only with established hierarchical assessment rubrics and rankings, but also with the ability of a knowledge ecosystem to support as many people as possible in reaching their potential and, in the process, create significant societal innovation (Crow, 2015; State, 2019; UMBC, 2016). The co-conceptualization of the NYC Applied Sciences Initiative by government, industry and academia brought industry experts into the conversation who had significant daily experience with discontinuity, disruption, and unpredictability (Corporation, 2010). The Initiative advanced the concept of professional education as a cross-sector, life-long learning endeavor supporting continuous socioeconomic innovation (Mulas, 2016). Many elements of the Applied Sciences Initiative are also found in other successful, cross-sector innovation districts (Katz, 2014) in cities like Boston (Project, 2015), Atlanta (G. Tech, 2019) or in initiatives under development like the Virginia Tech Innovation Campus in Alexandria (V. Tech, 2019). International forums relating to the future of work and future of talent (i.e. the Future Talent Council) are now deliberately structured as cross-sector efforts and are proposing transformational concepts including collaborative credentialing across industry and academia (F. T. Council, 2019). The recently announced additive manufacturing alliance led by the Robotics Institute at Carnegie Mellon University (Walters, 2017) achieves a level of connectivity that was unimaginable even 10 years ago. The alliance spans many stages and types of learning across multiple learning institutions (K-12, community colleges, research universities) and integrates these institutions with diverse industry and government efforts for inclusive socioeconomic development for the 21st century. The alliance takes entities that are considered to be competitors, like different universities, or entities that are siloed, like community colleges and universities, and allows them to instead be collaborators in very large team efforts.

2.2 Quintuple Helix Knowledge Ecosystems

The above examples propose that Quintuple Helix transdisciplinary/trans-sector knowledge ecosystems can potentially cover the full spectrum of 21st century knowledge needs presented in our introduction. Such ecosystems integrate industry, academia and government perspectives (the three sectors of the original triple helix (Etzkowitz, 2000)) with the contexts of civil society and socio-ecological environments (Carayannis, 2012, 2014, 2019). These knowledge ecosystems have the diverse expertise and experience necessary to compile, propose and experiment with highly differentiated and interrelated knowledge production and management practices. The notion of diverse knowledge ecosystems being responsible for transformative knowledge advancement is of course not new. It spans cosmopolis (universe-city) examples such as Babylon in 2000 BC, Athens around 500 BC, Rome

and Alexandria in Roman times, Florence and Rotterdam in the Renaissance, Vienna in the 18th century, Paris and Berlin at the turn of the 20th century and Silicon Valley in our current times. Although many of these ecosystems were and are place-based (i.e. current innovation districts taking advantage of the density and connectivity of an urban metropolis), it is possible that in the future they may also take the form of distributed alliances (i.e. the additive manufacturing alliance mentioned above or the UN Climate Change Partnerships (Nations, 2019)). Some of the current cross-sector paradigms are technology and science centric (Mulas, 2016). However, future knowledge ecosystems advancing innovation in tandem with socioeconomic and ecological sustainability will require "pluralism, diversity, and heterogeneity of knowledge" (Carayannis, 2014). The complex societal discourse of these ecosystems will rely significantly on humanistic and artistic experiences that cultivate multi-perspective reflective practice.

Quintuple Helix knowledge ecosystems anchored by comprehensive universities will have a significant part of knowledge production and management needs covered, but will need to rely on contributions from other sectors to cover the full spectrum of 21st century knowledge needs. These cross-sector influences may actually help innovate the universities themselves and the relation of universities with society. For example, in the late 1800s, a government/academia collaboration in the US resulted in the innovation of the land-grant universities which embraced a utilitarian role with access and opportunity for the working and middle class. This innovation required knowledge discovery and dissemination practices with key differences from the British Oxford/Cambridge model inherited by some of the first set of American Universities (e.g. Harvard, Yale etc.). However, the interplay of these different institutions, and their differing knowledge practices, enriched the evolution of American universities and promoted productive cross-influences (Cole, 2009; Graham, 1997). Similarly, the embedding of some modern universities in the cross-sector influences of Quintuple Helix knowledge ecosystems can result in the emergence of permanently dynamic institutions that can expand their knowledge practices while also maintaining many of the existing successful attributes (Thrift, 2016).

The cross-sector and cross-discipline interdependences of the proposed knowledge ecosystems can however give rise to concerns. Academics may worry that they will lose their independence, or that the academic agenda will be dictated by external forces such as industry or market demand (Gumport, 2000). We agree that these interdependencies may indeed blur distinctions between disciplines, institutions and sectors of knowledge and reduce the dominance of any one implementation structures (disciplinary departments, standardized curricula and tests etc.). However, these ecosystems will also increase independence for the individual knowledge practitioner.

Imagine a future Quintuple Helix ecosystem using small knowledge units (i.e. 1 credit course modules) with outcomes ranging from established (i.e. mathematical integration) to exploratory (i.e. iterative improvement). Stronger links connect proximal knowledge units (i.e. math modules with each other and with computer science modules) while weaker links connect units that may be more distant but potentially innovative in their combination (i.e. computer science and design) (Watts, 2003). These modular experiences are complemented by longitudinal studio based and/or apprenticeship experiences (C. D. P. Faculty, 2019). Learners approach content

through modes of delivery, order, and at a pace that makes sense to them. They can combine learning experiences across all types of institutions participating in the ecosystem: K-12, community college, 4-year universities and colleges, graduate study, or professional study combined with work experience. The connection of knowledge experiences into learning pathways prioritizes the discovery of individual strengths and interests while allowing the student to acquire missing knowledge components in a just-in-time manner across their lifespan. Learners may not need to first acquire a whole gamut of standardized proficiencies before focusing on their specialized strengths. Thus, education moves away from the negative notion of standardized deficiencies and focuses instead on the positive notion of personalized efficiencies (Davidson, 2017). Learning is assessed at the level of each knowledge experience but also at the level of the pathway. The pathway assessment integrates higher-level knowledge outcomes that are transferable (i.e. communication, collaboration, creativity) (Universities, 2015). Allowing individuals to explore the full spectrum of pathways (from fully standardized to fully adaptive) advances agency and active learning and gradually promotes a rich space of standardized/adaptive hybrids in the middle of the spectrum. Data resulting from this inclusive approach to learning across a Quintuple Helix ecosystem can be used to train computational tutors and advisors with reduced biases which can then facilitate the scaling of adaptive learning to meet the needs of a diversified knowledge economy (Rikakis, 2018; Selingo, 2019). Although the above scenario may appear futuristic, some of these approaches are already being implemented. For example, the undergraduate curricula at Brown University in the US and at Waterloo University in Canada offer flexible, adaptive and cross-sector education pathways advancing student agency in tandem with standardized learning.

Academic professionals would also have increased agency. One of the main challenges in current academic structures relates to limited resources that cannot adequately address the increasing costs for high quality knowledge discovery and dissemination (Marcus, 2017). The sense of a zero-sum game (a limited pie that will primarily go to the winners) increases bruising institutional politics within academia (Harris, 2016). As discussed earlier, the dominance of traditional bureaucracies, such as disciplinary departments, in all rewards and incentive structures further enhances this problem. In contrast, the proposed Quintuple Helix ecosystems can create a wealth of available and evolving resources, as well as knowledge development and management pathways for participating knowledge practitioners. These ecosystems will not hierarchize science over humanities or arts and will not give priority to legacy structures over emerging structures or to homogeneity over heterogeneity. This egalitarian approach will hold true for all attributes of 21st century knowledge and penetrate all relevant incentive and reward structures; from financial support to appointments, awards, and review of publications and grants. The only constraint for the knowledge practitioner will be their imagination and their ability to form and /or participate in cross-sector partnerships supporting existing and new ventures.

Quintuple helix transdisciplinary knowledge ecosystems can also result in partial liberation from dominant administrative structures and bureaucracies such as the disciplinary department. For example, the Olin College of Engineering emerged from an industry, philanthropy and academic partnership that eradicated departments while remaining a high quality, highly ranked college continuously gaining in innovation stature (Miller, 2010). The Olin model advances a diverse community of engineering

practice responsible for all aspects of engineering; from the disciplinary to the transdisciplinary, the established to the novel and the theoretical to the applied. Faculty members can inhabit any part of these continua at any given time, based on their evolving knowledge interests. The identity of the academic practitioner emerges from their practice rather than their fit with established categories (e.g. disciplinary department or industry sector) (De Weck, 2011).

Dynamic organizational approaches can raise fears of employment security. The open-mindedness and the embrace of intellectual risk required from a transdisciplinary knowledge practitioner can be undermined by the uncertainty of an annual or other short-term contract. Aware of these challenges, professional organizations combining industry and academic perspectives, are already advancing solutions combining job security with support of dynamicity and agency. For example, the Emory University School of Medicine gives its junior faculty members 11 years to choose between research, teaching, or research and teaching tracks and decide if they want to be considered for continuing appointments. Faculty can switch tracks at any time (S. o. M. Faculty, 2017). Carnegie Mellon and Stanford Universities have policies allowing faculty to structure contracts spanning industry, government and academic employment. A 2008 NSF report on transformative change in academia, proposes the notion of faculty "free agents" with continuing contracts and the ability to switch organizational units (Hartesveldt, 2008). Allowing knowledge practitioners to easily move and redistribute their efforts across different tracks, different knowledge cohorts and different sectors (industry, academia, government, society); increases agency, creates multiple paths for job security, expands the notion of "expert" in an inclusive manner (Guattari, 1972), resists artificial hierarchies (i.e. teaching vs research or tenure vs non-tenured) and avoids competition or talent grabs (Gibney, 2016) across ecosystem sectors.

The actualized multi-perspective practitioners of Quintuple Helix Ecosystems will be able to form diverse and inclusive cross-sector grand partnerships around complex societal issues. The rich discourse resulting from these partnerships will evolve gradually and support pluralistic societal wisdom. The knowledge and practices of the individual participants will evolve faster so as to keep up with the changing pace of socioeconomic structures and technological tools. Mid-level organizational structures (i.e. learning pathways, expert cohorts, assessment structures) will emerge as knowledge practitioners focus on connecting dynamic individual practice to gradually evolving large-scale transdisciplinary explorations of societal significance. Building on relevant prior work (Swearer, 2015), we define these organizational structures as knowledge platforms: conceptual models built to deliver particular knowledge practices (including values, goals, and processes) with as little attention to, or interference from, the platform as possible.

3. Conclusion

There is a growing mismatch between the knowledge outcomes of traditional universities and the knowledge needs of 21st century society. We propose that dynamic, transdisciplinary/trans-sector grand partnerships in the form of Quintuple Helix knowledge ecosystems have the diverse expertise needed to develop knowledge production and management structures covering the full spectrum of these needs. The interdependencies of these ecosystems can enhance creativity, promote sustainability

and increase the agency of knowledge practitioners. Anchoring these partnerships with comprehensive universities can provide a solid foundation for the ecosystems and facilitate the progress of universities towards more dynamic institutions. We acknowledge that the realization of these ecosystems faces significant challenges. Successful existing practices need to be integrated with novel, experimental practices. A sustainable inclusive discourse is needed that trains knowledge practitioners who can leverage the interactions of radical differentiation rather than let differentiation lead to fragmentation. We therefore propose experimentations with Quintuple Helix ecosystems as only one of many possible avenues for exploring the complexity of 21st century knowledge. The results of these experimentations, although potentially different from the predictions proposed in this paper, will advance the imagination of the involved communities and open new perspectives driving further experimentation.

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