Beyond R&D: What Design adds to a Modern Research University

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Abstract

The government of Singapore is launching a new university, the Singapore University of Technology and Design (SUTD), that is scheduled to take in its first freshman class in April, 2012. SUTD, in collaboration with MIT and Zhejiang University, is striving to establish a 21st century innovation paradigm that recognizes the synergy between innovation and design. Many aspects of such an exciting development are of interest to engineering educators and particularly to design educators and two are covered in this paper.

One challenge addressed in this paper is the possibility for conflicting agendas between design-centric education and the goal of becoming a leading research-intensive university. An overview of research intended to address this conflict –that of the International Design Center that is jointly part of MIT and SUTD- is given. It is argued that, rather than conflicting, design-centric education and research-intensity are synergistic for a 21st century university. The second challenge discussed in some depth is the setting of "culture" for the new institution that encourages bold attempts to improve the world through technical innovation ("innovation culture") with breadth in national cultures ("global culture") bridging from Western to Asian perspectives. Relative to the latter item, a central feature are the "Eastern Cultural" curriculum items being developed by a second SUTD partner university - Zhejiang University (Hangzhou, China). The breadth of national cultures and a wide academic disciplinary base as part of the education process are postulated to be enablers for developing a strong 21st century innovation-leadership-culture for the modern research university.

Key Words: design-centric education, culture, research-intensive university, design research, design theory.

I. Introduction

The Singapore University of Technology and Design is underway to become the fourth government –sponsored University in Singapore taking in its first freshmen class in April, 2012. The University was first addressed in a 2008 report given by a commission which was formed in response to a request from the Prime Minister to study how to expand Singapore's post-secondary education system [1]. As a fundamental strategic point of view, the report stated:

> "There is growing demand for highly-skilled graduate manpower as our economy moves increasingly into **knowledge-based, high value-added** activities such as **research and development**." (Emphasis added)

The major recommendations given by the report were: 1) to establish a mid-sized university offering a focused selection of disciplines; 2) to utilize international collaboration (forge a strategic alliance with a high-quality university overseas); 3) to take an integrated, interdisciplinary approach; and 4) to include exposure to real-world experiences. The Singapore Ministry of Education (MOE) has followed these principal recommendations and has chosen MIT as the international partner. The MIT proposal to the MOE included establishing SUTD as a research-intensive university utilizing a technology and design-centric pedagogy in its educational approach. The planned curriculum builds upon a solid foundation of sciences, humanities and engineering fundamentals in the freshmore (freshman + sophomore first half), a cross-disciplinary approach with core subjects and electives cutting across disciplines and a focus on a broad view of engineering and architectural design are part of this strategy. Nuggets of advanced technical electives across pillars foster further engineering and architecture interaction and yet provide depth in certain domains of specialized interests.

President Tom Magnanti has stated the aims of SUTD in his address [2]

"As an Institute Professor and the former Dean of Engineering at Massachusetts Institute of Technology (MIT), I have had the privilege of working with some of the most talented and creative people in the world and been immersed in an organization that bubbles with enthusiasm and has a passion to literally change the world. MIT does this through first class scholarship, the development of big and important ideas, a deep commitment to educating the most talented students to be found anywhere, and an unwavering commitment to sustaining a culture of innovation, leadership and entrepreneurship. MIT's motto Mens et Manus (Mind and Hand) highlights its simultaneous engagement with the world of ideas and the world of practice. The ideas are represented by numerous scientific, technical and other contributions, far too numerous to mention, and world of practice is reflected in part by the fact that MIT graduates have formed

over 18,000 companies throughout the world that supply important products and services every day.

Simply put, SUTD's aspirations are no less. Technology and design are essential to the world's well being. These fields offer enormous intellectual challenges and opportunities as well as an unparalleled occasion to impact and lead practice in Singapore, the region and the world. Through creative research and education anchored on technology and design, SUTD aims to create a new type of technically-grounded leader and inventor, one fully equipped to address the challenges and issues of today and tomorrow. Moreover, being anchored in Singapore and Asia, the University will be superbly positioned to capitalize on the world's fastest growing economy and to become an important research, technology, and learning hub. SUTD's emerging motto, The Art and Practice of Design, nicely captures its full embodiment of mind and hand."

Thus, Singapore is establishing SUTD as an element of its plan to move even higher in the value-added hierarchy of a knowledge economy and SUTD explicitly recognizes the importance of design in achieving this goal. Design as translation of new research findings to useful products fulfills this goal. Design as devising unexpected new products that give customers wholly new reasons to buy them as described by Verganti [3] also fulfills the goal. The broad view of design taken by SUTD encompasses these meanings of value-added and stresses the practical connection to industry and the economy overall.

Singapore is a country where such an innovative educational project is possible partly because of past success that has led it to being the country in Asia with the highest GDP per capita (well above Japan and at US or above levels). Indeed, among other countries that have developed rapidly over the past few decades, Singapore has emerged as the strongest in an economic sense (Figure 1a). In addition, Singapore has had great success in recently achieving a comparatively strong technologically relevant scientific base (figure 1b). It is also clear that the education system in Singapore has been very strong in science and math education and achieves a high degree of capability in this regard [6]. There have been concerns expressed about the tendency to base all measures of success on tests which some believe decreases capability to achieve less clear-cut and open-ended achievements [7] perhaps including new innovative companies and inventions. Indeed, there appears to be a shortfall in practical inventive output relative to the same comparative group when patent data instead of publications or GDP per capita are compared (Figure 1c). Thus, SUTD's mission and goals are an integral part of how Singapore plans to meet its own definition of its needs.

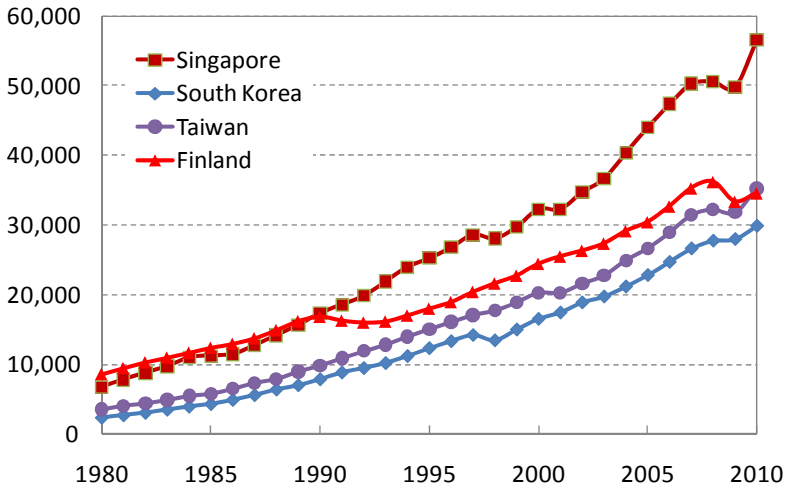

Figure 1a) Per Capita GDP (Current International Dollars) based on Purchasing-Power-Parity (PPP)-data from [4]

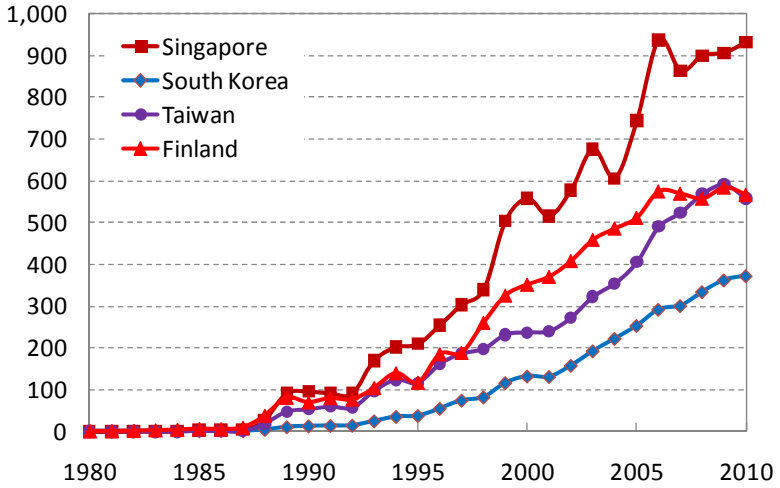

Figure 1b Engineering Journal Articles per Million People- data from [5]

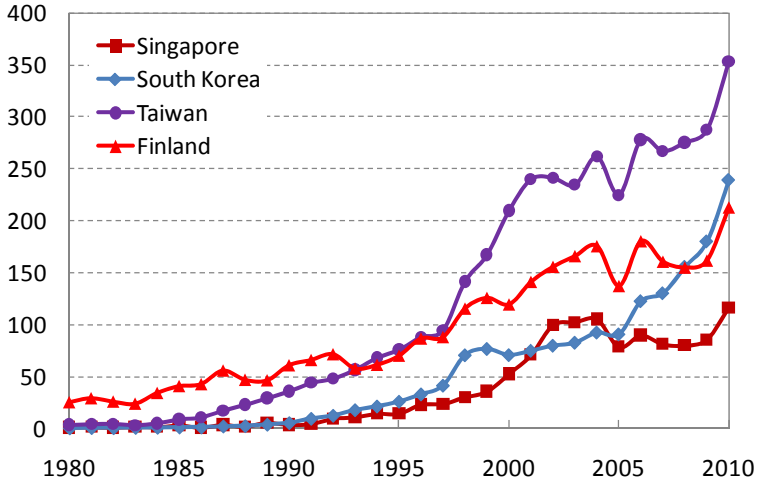

Figure 1c U.S. Patents per Million People –data from [8]

This paper will consider several aspects of SUTD's vision. In particular, two will be looked at in some detail:

1. The nature of and potential for establishing a "culture" within SUTD that is different from that existing in other universities in Singapore;

2. The dual concepts of anchoring the education on technology and design while being research-intensive.

In Section II, some of the conceptual challenges involved in establishing a new culture will be explored while Section III selectively covers the activities for addressing these issues. In Section IV, potential conflicts between design-centric education and a research-intensive university are explored while Section V uses the research approach of the SUTD/MIT International Design Center to argue that the two can be synergistic. Section VI draws the themes together in a closing section.

II. Culture Definitions and Fundamentals

The term culture is widely used and thus is subject to various meanings. Indeed, Alfred Kroeber and Clyde Kluckhohn famously compiled a list of 164 definitions in *Culture: A Critical Review of Concepts and Definitions* [9]. One of the operative definitions used by social scientists is employed here: *the set of shared attitudes, values, goals, and practices that characterizes an institution, organization or group*. We will be considering SUTD (students, faculty, staff, etc.) as the institution whose culture is being explored. However, SUTD exists within a Singapore, an Asian and a global cultural framework that will influence SUTD.

An important fundamental is the fact that culture is a holistic concept. Thus, changing any singular practice, goal or value is not likely to enable formation of a very different culture and may simply introduce a kind of dissonance where the new practice is eventually ignored. Similarly, the culture of an institution as noted above is affected by the surrounding environment. A second important fundamental is that human culture is highly connected with the power of humans to use abstractions and thus how people view the world and communicate about it is central to the concept of culture. Of course, it is not necessary to change all aspects of how people see the world to effect significant change.

In this regard, we see the SUTD cultural mission (based upon the material in Section I) as enabling the emergence of "a new type of technically-grounded leader and inventor". This will apparently require more risk-taking and less clear cut simple output measures than are the current norm in Singapore. An important element involved with achieving this will be the enhanced multi-disciplinary approach inherent in the SUTD structure and curriculum (no departments or schools and many common

courses including those in humanities and social sciences). It may also require more self-starting than is the current norm.

A second key aspect of the SUTD cultural mission is involved with realizing the potential of being (as noted in Section I) "*superbly positioned to capitalize on the world's fastest growing economy"* clearly means having a deep understanding of China. Indeed, having a strong multicultural understanding is perhaps implied by the "*new type* of technically-grounded leader" in the preceding paragraph. Design outcomes that reflect deep multi-cultural concerns are likely to be important elements of successful design and innovation during the coming century.

III. SUTD Initial Approaches in Culture Building

It is yet almost a year until the first SUTD students arrive on campus and it will be a number of years after they graduate before some aspects of the success of SUTD's culture building can be assessed in a realistic manner. Nonetheless, such initiatives cannot start too early and thus have been a major aspect of SUTD efforts since the very beginning. Indeed, the approach Singapore is following- formation of a new university rather than expansion and transformation of an existing institution- makes possible greater change only if the intention is followed from the beginning. Faculty recruitment, student internships and teaching related to these internships, administrative practices, governance, promotion criteria, "entrepreneurial ecosystem" development, student recruitment, staff recruitment, curriculum design, academic organization, classroom pedagogy plans, campus design, co-curricular activities (student living, student governance, teams, etc.), research group mixing, faculty space sharing and many other aspects are all being considered as part of the culture building endeavor. Indeed, the prescription to be holistic relative to culture building is now "part of the culture" at SUTD. It is not the aim of this paper to discuss all of these activities but only a few that might be illustrative of the overall effort.

SUTD has recruited a modest number of the students that have been accepted and who will attend SUTD beginning in April, 2012. Because of timing of some acceptances, this practice was actually able to start in the fall of 2010 with the hiring of a few research technicians who as an extension of MIT's term for its highly successful Undergraduate Research Opportunities Program are called by some BUROPs [B(efore) UROP]. This program –seen as cultural seeding- has been extended to a number of offices in the university as space and faculty hiring allows and by May 2011 includes more than 20 (pre)students. The (pre)students, under a framework called "the campus builders program", are working on student governance, campus design, co-curricular activities, course development, student recruitment, and other activities as well as research. Their feedback has been helpful in a wide variety of issues and much effort has been made to have them make real contributions and to act in "fully-empowered" ways. Selected participation in visits to SUTD's partner institutions (MIT and Zhejiang University) to

explore effective culture transfer is also part of the planned utilization of the students.

Two other aspects of the culture building activities at SUTD are worth briefly noting. One is that many of the initially hired faculty[1] are being "seconded" to MIT for one year. Although these efforts are labeled "Teach-the Teachers", they involve not only much interaction with the course developers for the specific course that these faculty are going to teach but also a series of introspective activities exploring MIT from various viewpoints (student, admissions decisions, overall leadership, faculty, research groups, interdisciplinary research leadership, historical, etc.). The newly hired faculty and others educated in Singapore are asked to identify potential differences between MIT and Singapore for educational practices and attitudes. Subsequent discussions of importance (or possible value positive and negative) of differences are held in an attempt to systematically identify issues to be addressed.

An ongoing longitudinal study of student cohort development that explores many "cultural issues" is being extended to SUTD (and Singapore)[2]. Findings from this study are expected to deliver valuable longer term feedback on the culture building aspect of this new University.

A final aspect of the culture building activity is covered in a little more depth. Given the major role of MIT in developing SUTD (course and overall curriculum development, research partnerships, student governance, accreditation of degree programs, co-curricular programs, faculty selection, the President's long MIT career, etc.) and a clear attempt to emulate some of MIT's strengths, a Western influence on SUTD is assumed as a given. The Asian/Chinese connection is being provided by a second partner institution –Zhejiang University. To foster more interaction and provide SUTD students a deeper understanding of the Chinese working and business environment, about 100 SUTD students will be sent yearly to ZJU for educational exchange as well as internships in the Hangzhou area. This unique opportunity allows SUTD students to build early partnerships and networks, and to explore the entrepreneurship and business environment in the ever changing and exciting economy of China. As a major aspect of the cooperative agreement, Zhejiang is developing a set of five electives whose preliminary description is below.

- *Business Culture and Entrepreneurship in China*:

  This course focuses on business culture, individual, team and firm-level entrepreneurship in China. As the course explores the culture of business in China, the rules guiding entrepreneurship, institutional holes and double entrepreneurship will be explained. The course will provide a deeper understanding of the country's institutional change and entrepreneurial strategies, its entrepreneurial process, the

[1] Indeed all 7 of the first hired and arrived faculty departed from SUTD in January, 2011 for a one year stay at MIT
[2] Professor Susan Silbey (of MIT's anthropology section) is conducting long-term longitudinal studies of MIT, UMass, Olin and Smith students and is adding SUTD and several other Singapore universities to this study

limits on playing institutional holes and the key players involved such as the entrepreneur, the bureaucrats, and the journalists. Entrepreneurial authority and institutional autonomy in China will also be addressed as part of the course.

- *Culture Formation and Innovative Product Design*

Focusing on the origins and development of China's traditional appliance design thinking, this course will start with an introduction of the design characteristics of each dynasty including an appreciation for embedding cultural phenomena and the evolution of Chinese culture. Furthermore, the course will analyze the design methodology from the perspective of a full range of design thinking such as design principles, structure design, materials techniques, visual design, design comparison and design thinking. From these historical studies, the integration of such knowledge will be used to develop a proposal for innovative design ideas that will culminate in a modern industrial product design.

- *History of Chinese Urban Development and Planning*

The course is based on the environmental concepts of ancient Chinese cities and settlements to reveal the ecological implications of building and development against the backdrop of ancient Chinese culture. The principles of Chinese architecture are rooted in the ideas and applications of Feng Shui and have largely remained unchanged over time compared to the architectural systems in other cultures. There are two pertinent issues in the study of Feng Shui today: how historical buildings can co-exist within the modern city context and how the ancient architectural designs and traditions can complement modern architectural designs. The course attempts to respond to these issues through both examples from the history of architecture and through exploring specific designs of modern buildings.

- *The Role of Technology and Design on Growth of Modern China in the 21st Century*

Modern China's achievements especially since the economic reforms and opening up of the country can be viewed as a brand-new economic and social development mode for the world. From the new process of industrialization with Chinese characteristics, this course will examine the role of technology and design in the past, study it in its current context and explore future possibilities. The relationship of society, commodity, technology and design throughout China's economic reforms and technology and design as an indispensable industry resource will be covered. This course will also introduce and emphasize the current status of China's design industry, the role of design organizations in the local economy, and the operation and management of design activities.

- *Sustainability of Ancient Chinese Architectural Design in the Modern World*

There are four parts in this course: Chinese ancient architectural design, Chinese-themed landscape planning and design, construction and use of materials and their sustainable use in today's context. Firstly, Chinese ancient architectural design introduces the rich design history behind different kinds of buildings such as palaces, temples, houses ranging from city, hillside, riverside and village amongst others. Secondly, Chinese-themed landscape planning and design focuses on the aesthetic theory of Chinese literature, paintings and poems and how they influence Chinese landscaping. Thirdly, construction and use of materials mainly introduces wood structural methods and techniques. Finally, sustainable development in today's context includes examples using different kinds of construction methods such as wood structure, concrete structure, steel structure etc to express the Chinese architectural development in a modern context and in the various styles such as classical, postmodern, compact, or abstract.

These five courses thus cover a broad range of material relative to Chinese historical, technological and business knowledge with emphasis on the innovation economy. Further reinforcement of the course material and depth of knowledge of China will occur through the planned student exchanges and internships at Chinese companies by SUTD students that were discussed above. In addition, students from the three institutions will jointly participate in design competitions hosted by MIT, SUTD and ZJU on a rotational basis. This will foster increased cultural interaction.

IV. Design Research Definitions and Issues

Design- like culture- has many uses in common language and is an essential concept concerning human life. While the authors know of no publication that lists all alternative definitions of design, perusal of any dictionary shows widely differing multiple meanings and uses. A fairly simple but broad definition due to Simon is utilized in this paper "design is transformation of existing conditions into preferred ones" [10]. In almost all aspects, this definition is consistent with the description given relative to "Big D" –the term used by SUTD in its thinking about design which has three elements marking inclusiveness ("Bigness"): 1) Includes architectural design, product design, process design, software design, systems design, service delivery design and basically all technically grounded design; 2) Design through conception, development, prototyping, manufacturing, operation, and maintenance – the full value chain; and 3) Includes Practice (Art) and Research (Science) [11]. Although Simon's parsimonious definition does not include "technically-grounded", it is clear from the essay that contains his description that he would not object to having technically grounded enter a broad definition of design and it certainly is present in our meaning for design.

Of potentially more controversy is the concept of "design research" or even more

broadly combining research-intensity with design-centric education. That this is an issue is indicated by 1) papers that describe the interference of "research-intensity" criteria for promotions etc. with having design-centric faculty [12] and 2) by the lack of doctorate programs in most design-centric post- secondary schools such as Harvey, Mudd College, Olin College, Cooper Union, Rose-Hulman Institute and many polytechnics globally. We will return to this second issue in Section V but for now summarize some other issues of importance in the design-centric mode of teaching.

Although there is some (limited) evidence that conceptual learning and retention are both enhanced by using design-centric pedagogy [13, 14], there are strongly felt reservations about how far design-centric learning can be effectively applied in teaching the fundamental science and math courses. Further issues arise from the fact that design appears highly context-specific and thus may not be appropriately taught in similar ways to people who end up participating in different engineering fields. Especially among experienced designers [15], there is a strong feeling that design is highly non-systematic. Thus some in academia question whether design can be taught and even whether it has value in the curriculum. These debates can be extremely heated – possibly reflecting the almost negligible amount of solid evidence that can be mounted in support of ***either*** position.

V. SUTD Activities in the Design Research Domain

Recognizing the strong value of design in achieving the overall economic development objectives of Singapore and the issues raised in the preceding paragraph, SUTD as designed by MIT and the Singapore Ministry of Education, established its first and central[3] research center as the International Design Center (IDC). This section will give an overview of the IDC discussing its objectives, structure, initial research agenda and desired outcomes. It will seen to be *designed* to attempt to address the major issues raised in the preceding paragraph and in doing so give a very positive answer to the question of combining design-centric education and research-intensity.

IDC has significant resources – MIT will be able to support about 25 research personnel and SUTD about 50- and is funded for 10 years (review at 5 years). The basic structure of the program is that leaders from MIT and SUTD oversee projects of two basic orientations –one utilizing design to address key societal problems (Grand Challenges) and a second orientation that focuses on studying aspects of design (Research Thrusts). IDC is simultaneously practicing design (Art) as it does research on the design process (Science). Figure 2 represents the two dimensions and shows the initial set of grand challenges (rows) and research thrust topics (columns).

[3] This has intellectual as well as campus design meanings as the IDC will occupy a highly visible and central position in the new campus planned for 2015.

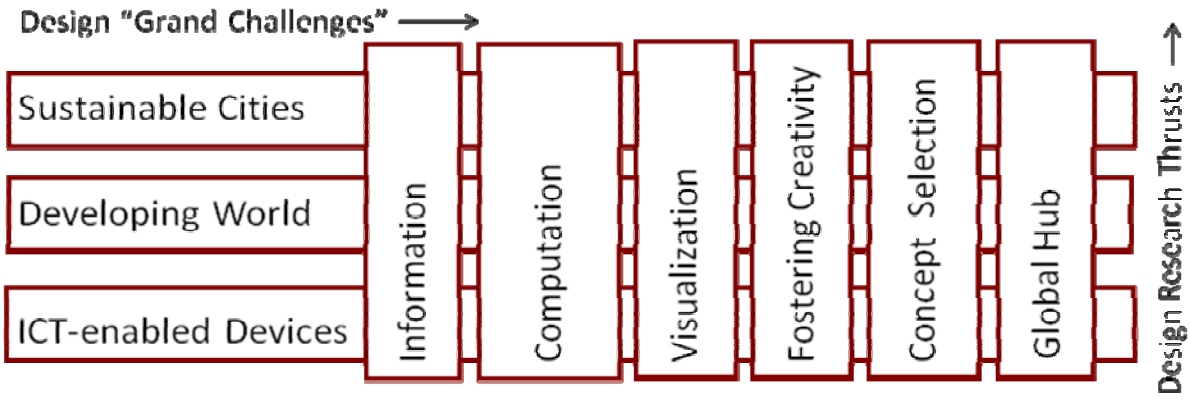

Figure 2: A Matrix of the Grand Challenges and Research Thrusts active in the IDC

The set of design research thrusts (the "columns") are intended to be a partitioning of the activities needed for outstanding design. Information structures the design process as data on customers and technologies help define the design targets, experiments and simulation add needed information during product development, and information technology organizes the information as it accumulates during operation, servicing, and end-of-life. Computation is the most rapidly developing tool for extending the information useful for design and is the major driver for change in practical design processes. Visualization is essential for making use of the information in further design efforts by the design team and for communicating it to other stakeholders such as clients. Creativity and Concept Selection together create a process of divergence and convergence as new alternatives are developed to expand a set and then a critical evaluation subsequently reduces the set to a more manageable size. The "Global hub" enables collaboration generally within a design project and emphasizes that occurring within and between companies to ensure successful design when co-location is infeasible or undesirable. The partitioning was done partly to help recruit faculty to the various leadership positions but the research is to be performed both within columns and rows, and between columns and rows.

There are five objectives fixed since before any work commenced that support the overall IDC vision:

1. Advance design theory and methods
2. Use design to address key societal challenges
3. Integrate the above two – connect design research and practice
4. Serve as a nucleus for growth of SUTD as a research-intensive organization
5. Enable the long-term innovation in SUTD curriculum

- A source of new ideas for design education, methodology, tools, and practices
- Catalyze teaching innovation

All of the objectives are important but for the purposes of advancing the state of knowledge ("science") concerning design, objective 1 is particularly critical. Indeed, some scientific understanding of design is in existence (for example summaries, see [16] and [17]) but has been insufficient to convince skeptics. Indeed, it is worthwhile considering some of the "agreed- upon" fundamentals about design before considering the IDC approach.

One of the most important fundamentals of the design process is that success requires many (faster is better)[4] failures. This fundamental can be expressed using the title of one of Henry Petroski's books *Success through Failure: the Paradox of Design* [19]. However, as Petroski explains for an evolutionary or learning process, trials and thus failures are required so arriving at something new *requires* failure alleviating the apparent paradox. To use an Einstein quote: "Anyone who has not made a mistake has not tried anything new". The various ways that the trials are evaluated and then lead to new ideas and new trials is broadly captured in the concept of "cycles of divergent and convergent questioning" [17, 20]. The subtlety and complexity of these cycles is not something done by a consistent, systematic process but probably instead by a rich and powerful "toolbox of heuristics" [21, 22, and 23]. Thus, a second fundamental of the design process is that it is *powerful* yet largely *non-systematic* (arguably a second paradox). Indeed, in keeping with this fundamental, there is evidence that the design process is enhanced by processes that are not highly structured -but have just enough structure- [24] rather than being analytically or logically over-constrained. A third fundamental and somewhat paradoxical aspect of design is that modeling is an important method of abstraction but that the models used for generating and evaluating design trial concepts are most often "quite stretched" metaphors and analogies. Examples of these have been known for quite awhile [25] but newer research [26] is linking design research to a rapidly advancing area of cognitive science (for examples, see [27, 28]. Although basically concerned with translating understood material to unknown or new problems, these generative metaphors are particularly powerful in allowing one to make "novel guesses" about the unknown. This third fundamental is easily linked to historical cases studied by cognitive scientists who often find "(disruptive) lateral cognitive moves" as central to the process leading to highly novel designs [29]. Two fundamentals that are not apparently paradoxical but that are easy to forget are: 1) the importance of deep knowledge –technological and scientific- for effective design [30, 31] and 2) the usefulness of distinguishing questions of what/why ("function, fitness or adaption") from questions of how ("mechanism, embodiment or form") [32, 33] when considering

[4] A very strong demonstration of this is in the interesting story about the importance of failure velocity is given in [18]

design activity.

We used agreed upon in quotes when introducing this set of fundamentals for two reasons. The first is that the evidence for these is relatively strong but not intensively supported by objective experimentation. The second is that even among design researchers that are in rough agreement, no list of fundamentals is agreed upon and the characteristics just delineated are not the only ways to describe design fundamentals.

IDC's contributions to this critical area are expected to arise from two sources where the center is arguably different from other research on design. The first is that the technical domains that IDC is participating in cover far more domains (see "Big D" discussion in the first paragraph of Section IV) than any existing work. While this arises from the SUTD breadth of design interests, developing common terminology and utilizing similar experimental approaches across design of software, electromechanical hardware, architecture, manufacturing, logistics and complex socio-technical systems is expected to force consideration of fundamentals of design as opposed to context. A second IDC strength is the breadth of the research leadership group of 10 people consisting of 2 architects, 3 social scientists and 5 engineers. While –like us- others have utilized cognitive psychologists in design research work, the simultaneous impact of other social scientists (anthropologists and sociologists) and the broad range of technical design fields combined with new empirical techniques is expected (by us at least) to significantly advance the field.

In meeting objective 2 – Use design to address key societal challenges- IDC intends to vigorously pursue (in a few selected cases) full *implementation* of our design ideas. Thus, we expect to contribute not only the idea but to make the designed system or object have an intended positive impact on society. We believe this will have educational as well as research benefits. Simon's definition of design (transformation of existing conditions to preferred ones) does not limit design to only early prototypes or "proofs of concept". Of course, we fully expect to produce far more potentially valuable concepts and prototypes than we can directly attempt to implement. Many of these concepts will go little further than "relevant science" but a large number will go to a "proof of concept" stage and a few to full implementation. In our initial work, the "Leveraged Freedom Chair" [34] is receiving an all-out effort for implementation because we see it having a very large beneficial impact on wheelchair bound people who live in less developed locations and because our researchers[5] are learning to be effective in linking to non-profit organizations that can see the benefit and the value of the design. IDC is also doing research on developing highly novel measurement and control modular systems (referred to as MICA[6]) that we believe have the potential to transform technical education at various levels and this is a second potential idea for fuller implementation efforts. Other areas for possibly implementing our design results

[5] In particular, Dr. Amos Winter of MIT who is now a postdoctoral associate of the IDC
[6] This work is centered in Professor Ian Hunter's Lab at MIT

may come out of diverse fields such as logistics or urban policy. Implementation will almost always involve partnering with private, governmental or NGOs to achieve our mutual goals.

Objective 3 –connecting design research with practice- is also important and is being pursued in several senses within IDC at present. First, the researchers in design thrusts are linking with research activities in Grand Challenges (GC) both to learn more about design and to contribute to the Grand Challenge goals. As an example, the computation research thrust is working with the ICT devices GC and their work is leading to a combination of MICA with "super-computing with a cell-phone"[7] that may greatly enhance the value of MICA. A second sense of connecting research with practice is that the various researchers are expected to interact with industry and government agencies which have design responsibility to mutually identify problems and implement solutions that come from the research efforts. This kind of work is common at MIT and is identified already as a key goal of research and education at SUTD. Thus, the work is expected to interface with Singapore and Asian entities, as well as with U. S. and global organizations.

Objective 4- serving as a nucleus for growth of SUTD as a research-intensive organization- is obviously important as research-intensity is a major goal for SUTD and the MOE and thus may be the most important of the objectives. If the efforts end up decoupled, the funding of a joint center between MIT and SUTD will then not be very meaningful. An important mechanism to foster jointly performed and published work is a series of residencies for key MIT faculty at SUTD. Over each five year period of the IDC research, the leading IDC/MIT faculty will reside in Singapore for short and long periods averaging about 12 months for most faculty and full-time residence for the IDC co-director(s). In addition, the aim will be to have the majority of the work co-performed by MIT and SUTD personnel and to have significant co-publication across the two universities. An important sub-objective of serving as the nucleus for research intensity is to utilize IDC results and interactions with various agencies and companies to excite others in the results enough to provide significant additional funding.

Objective 5 commits the research center to doing research and achieving significant results on design education pedagogy. This commitment to significant new research on design pedagogy is fundamental to beginning to answer the questions about how to teach design. Having this research embedded in a wide-ranging effort to practice design while studying the fundamentals of the design process ensures its applicability in ways not easily done in any other way. In addition, the breadth of the academic disciplines used in the research and the breadth of domains for practice of design also maximize the potential validity and applicability of this research. Overall, the research planned in this area as well as that underway against objectives 1 and 3 is the basic structure of the IDC design that addresses the issues in the final paragraph of Section IV.

[7] This work is being led by Professor A. Patera's lab at MIT

We have hypothesized in several places that the breadth of disciplines involved in the research and education is an essential enabler of achieving the goals for the IDC- especially in objectives 1 and 5. We have also argued that the breadth of application areas (design practice domains) is equally important in achieving these key objectives. It is a bit more speculative but possible that the prior de-coupling of design-centric education and research-intensity results from a narrower set of domains and disciplines at prior institutions than that envisioned in IDC and SUTD.

VI. Closure

This paper has covered two of the issues being addressed in the attempt to develop a 21st century technical-innovation-oriented university. The two topics chosen-culture change and design-centric education coupling with research intensity - are of course not the full set of issues being addressed in this exciting and challenging initiative. However, we believe that they are among an important smaller set of key issues and in this section explore some interactions between these two topics.

One perspective for viewing interaction between the two topics is that increased design capability requires greater mental flexibility. Thus, having a design oriented faculty and student body should be convergent with a desire to achieve cultural change. Moreover, in a very real sense the desired results of important design efforts are in fact broad cultural changes. Thus, it can be hypothesized that a design-centric university is more capable of establishing a different culture than one that is not design-centric.

As discussed in Sections II and III, culture change is challenging because of its holistic character and the fact that the target institution is embedded in an environment that cannot (nor necessarily should) be totally changed. The existence of design-centric education and research-intensity is apparently not existent at present but these approaches may possibly be synergistic if design research is a central part of the research endeavor. Thus, we can also hypothesize that research intensity coupled with design-centric education is a further enabler of cultural change.

It is often apparently perceived that the scientific process is much more systematic than the design process. However, for conceptualizing *breakthroughs*, it is clear from extensive analysis [30, 31, 35, 36, and 37] that non-systematic but powerful approaches are used in both design and research. Thus, *design* and *research* –arguably the two most powerful processes driving societal cultural change- might be viewed as being much more similar than they are generally perceived.

The sub-title to this paper (What Design adds to a modern research university) appears to be answered by "a stronger basis for research and for translation of research results to human use (essentially translating knowledge to culture)". However, consideration of an equally apt title demonstrates the double interaction inherent in our topic choice. "Beyond Pedagogy: What Research adds to a modern design-centric education

institution" is such a possible title. The answer argued for in this paper is that research on design can lead to deeper understanding of the fundamental process of design-beyond how to teach but instead *what* to teach and mentor in order to effectively teach design and what it enables -innovation. Demonstration of the synergy of the *Art* and *Science* of design is therefore the most persistent theme of this paper.

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