3D PRINTING FOR MULTIDISCIPLINARY EDUCATION: A TECHNOLOGY WITH DIVERSE POTENTIAL

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Abstract

The invention of 3D printing is giving rise to a new era of innovation and creativity in manufacturing. The widespread integration of 3D printing into myriad processes and industries is taken as an indication this is the beginning of a new industrial revolution. Reminiscent of the first industrial revolution, educational changes are likely to accompany this vast transformation of work and society. New educational needs for succeeding generations are becoming apparent. For example, the specialization of industrial production into separate processes which is made possible through 3D printing, will require educational changes that prepare future generations for inclusive manufacturing and bringing marginalized society into the mainstream. In this new society, 3D printing should be understood not only as a technology, but also as a social instrument that will require new ways of thinking and co-operating. This article presented a summarized idea of how 3D printing could be successfully integrated as part of coursework in different disciplines such as math, science, history, geography etc. But just as it is important for engineers, historians, geologists, scientists, mathematicians, architects, technologists and other specialists to further develop 3D printing technology and its application, it becomes equally important for social scientists such as economists, business managers and language teachers to explore how this new industrial revolution will usher in a new social environment. Economists should investigate how 3D-printed related new business ideas and models could be explored, invented and implemented. Management coursework could explore how additive manufacturing-related processes might diversify and simplify group collaboration and coordination, production schedule, process and information management. Language teachers should research how procedural information about 3D printing-related processes could be executed and documented seamlessly following the technical writing principles. Academic departments can make use of 3D printing to initiate multidisciplinary approaches to teaching technology, social sciences, and human communication. Such a holistic approach to education will be the basis for re-conceptualizing education for business process management and teamwork, and instigate new approaches to promote innovation, marketing and leadership. In the globalized context of international trade and business, language teaching in real-life scenarios will help to prepare students for language use in multi- cultural business and industrial contexts. Such a multidisciplinary approach help students critically analyze opportunities and pitfalls that are integral to the 3D printing revolution aimed at international development and humanitarian response.

Keywords: Interdisciplinary, Information technology, 3D printing, innovation, diffusion, revitalization.

1 INTRODUCTION

The maker movement is only a decade old, but tool creation is an early form of human activity ([1]; [2]). The DIY (Do it Yourself) approach to industrial manufacturing has ushered in a new maker subculture that has integrated the hacker culture and the general acceptance and application of open-source hardware in classroom settings [3]. 3D printing is one important instrument of this DIY approach. 3D printing with its inclusive and compartmentalized manufacturing approach has changed the way we think about information and design management, sales, approach to design, production processes, marketing, and education. This new revolution using open-source design and 3D printing brings manufacturing to the desktop [4]. This change in real-world approach to doing things should be reflected in the education we impart. The biggest advantage for education with 3D printing revolves around its hands-on approach to manufacturing that empower students to design, collaborate, and create amazing artifacts with ideas, projects and activities in a classroom environment. This makerspace looks more like a workshop than a classroom and is consistent with the research stating that hands-on projects demonstrate a deeper understanding of concepts when compared with traditional textbook, lecture and test-based teaching [5].

Researchers and educators have long recognized the value of uniting the classroom and the makerspace. This approach helps to bridge the gap between educational theory and applications.

Reallocating computer technology budgets to technologies that require understanding and use of both software and hardware could help to make some subject areas more multidisciplinary. Applying conceptual knowledge to technical tasks could help to inspire students and accelerate their knowledge intake through innovative curricular applications [6]. The excitement that comes with handling actual physical equipment in the classroom such as 3D printers, 3D scanners and other associated design software may help to develop creative thinking and analytical reasoning, thereby motivating students. Such creative thinking contributes towards flexibility in curriculum design as well. The maker classroom embraces the idea of a lab or "activity" that moves the students away from standard textbooks, making them think independently and apply the concepts read in the books in a physical landscape. A standardized curriculum is then complemented by innovation and imagination in which students may more flexibly decide their projects.

There are numerous applications of 3D printing in education that have the potential to revolutionalise the classroom environment and curriculum design. Firstly, 3D printing provides teachers with 3D visual aids that could be used to explain very difficult concepts. A 3D representation of any object or concept acts as a hook activity that helps to hold on to student interest when compared to 2D representation of an object. 3D printing is a prototyping technology, and students in any major would be able to produce a realistic 3D mini model to represent a concept. Finally, the project-based approach helps with interactive class activities and iterations that help students learn from each other without unnecessary repetition.

This article begins by considering various "traditional" uses of 3D printing in education, and then discusses the possible pedagogical applications of the concepts and applications related to 3D printing in economics, project management and foreign language training. The pedagogical applications in economics, project management and foreign language education ideally focuses on the marketing concepts, societal models of innovation and related documentation of the 3D printing processes, and might not be directly related to learning from the physical artifacts created with 3D printing.

The purpose of this article thus is to explore how a broader understanding of 3D printing-based pedagogy will help to customize innovation and educational applications within a multidisciplinary framework. Multidisciplinary education with 3D printing is a topic of discussion in this article because researchers have ample evidence showing a direct link between art and creative thinking and cognitive abilities. There is an increasing acceptance of the manner in which science, technology, engineering and mathematics is being integrated into arts curricula and vice versa, and an increasingly popular way instructors are combining these disciplines is through 3D printing [7]. 3D printing has justifiably made STEAM (Science, Technology, Engineering, Arts, Mathematics) education more exciting and interdisciplinary.

The purpose of this paper is to provide a summarized understanding of how topics related to 3D printing processes; applications, economic implications and management could be included as coursework in various disciplines such as Economics, foreign language and technical writing, project management etc. This article made an attempt to address the following two fundamental questions related to 3D printing. (1) How could 3D printing-based processes, technology and socio-economic implications be taught as part of a wide range of university coursework? And (2) specifically, how could 3D printing be taught as a focused topic in disciplines such as economics, language studies and management?

2 3D PRINTING IN STEAM EDUCATION

Use of 3D printers in a math classroom is primarily a school-level application helping students to envision graphs and mathematical models. A 2D representation of numbers, graphs and equations on paper are sometimes difficult to comprehend for students who cannot imagine the context on paper and are deeply visual learners. However, a 3D-based tangible representation will help them see the angles, curves, and how the equations function with a physical object.

3D printing to understand geological formations is an excellent way to understand a specific topic in the subject area. Understanding rock formations, tectonic plate movements, craters and volcanic formations etc. has been very useful to depict a story of the physical structures on earth and other planets. 3D printing of the earthquake data helped to better compare earthquakes that happened in different places, and over time. Further, 3D printing has been applied to better understand and teach the use and effects of oil/gas fracking [8].

Museums see the potential in making 3D printed replicas of ancient artifacts and having student competitions and class projects where such replicas could be made. Replicas made and certified by the museums as true copies of the originals could be introduced in the history classroom where students can touch them, unlike in a museum, and have a feel for the time and people who used them. It is interesting to imagine a history class where students can learn about incidents that took place, the people and artifacts and are able to print some replicas of artifacts using a large database of .stl files [8].

Arts and design classes could be designed to be more interesting if students were able to 3D scan objects, perform usability testing of products for end-user applications, use 3D software to design objects for 3D printing, search the *Thingiverse* database for innovative design and improve on those.

3D printing for education has limitless opportunities and schools and universities have started to realize it [8]. It is a trendy genre focused on emerging tech trends in digital business and provides a valuable forum that can effectively discuss the different ways innovative technological innovations and applications enhance our social, collaborative, organizational and personal work environment. It's expected that some of the 3D printing-related applications in education that are commonly discussed will be at their infancy, some theoretically plausible but practically obscure, while some will be at a more mature stage for consideration, acceptance and implementation. Interestingly, what matters most is the balanced way we accommodate these applications in a 3D printing based educational context.

3 INNOVATIVE 3D PRINTING PROJECTS IN THE CLASSROOM

A 3D printing classroom provides immense opportunity for innovation and peer learning ([9]. Projects making use of 3D scanners enable students to capture measurements of objects and then innovate on the design using CAD software and then 3D-print them. 3D scanning is also a valuable tool used for reverse engineering purposes, thereby removing the classic division that exists between the customer and manufacturers. Class projects can ask students to customize a student's personal product using 3D scanning or internet research of a 2D image and then print a new one that can be easily identified as a modified or improved version of the earlier one. The easy availability of 3D scanning apps on Android, Apple or Windows machines makes it a lot easier to customize a product. Further stages of the same project or different projects can deal with computer modeling with CAD software such as Sketchup Pro, Tinkercad, and Autodesk Tinkerplay. Other interesting 3D printing applications in a classroom (as discussed in the literature) include printing speakers for iPods, teaching physical computing and fabrication, learning about aerodynamics by printing original toy drag racers, learning rapid prototyping, math and 3D visualization, and printing replacement parts for a robot ([10].

Mara Hitner [11] discussed an innovative 3D printing curriculum for at-risk English learners. This curriculum is for children who have trouble speaking and writing English. The idea behind the curriculum is to develop content that is interesting for children and can contribute to real-world creation. This classroom deals with project-based learning (PBL) units on 3D-printing e-NABLE assistive devices for other children. Part of the idea in this English language classroom is to assist students to acknowledge success and failure related to 3D printing processes through writing exercises and high-level cognitive reflection of the collaborative activities. Besides tracking the 3D printing processes and how they progress in the classroom, students also write formal letters to the recipients of the e-NABLE hands they produce. Hitner [11] also mentioned about a PBL method that include creating simple machines to help students think logically and analytically about the processes, design, execution, etc., and to write about sequencing.

An anthropology classroom can include activities such as digital reconstruction of partial skull and jaw. The files could be posted on *Thingiverse* for anyone to download and print.

Another article discussed an assignment where each student was to colonize a new planet and they received separate emails from people on that planet talking about particular problems. Students solved a problem by making a clay design and capturing it in 3D software and then printing a solution product based on their idea. One example of a planetary problem a lack of nutrients in the food on the planet. One student built a product in the shape of a stapler that would squirt nutrients into the food [12]. The cutaway earth science project is a perfect way to expand on the earth science concepts by exploring the various layers of the earth. Meteorology through a 3D printed and embossed Hurricane Patricia is a wonderful physical depiction of the storm system as seen from satellites. The K-12 design project of a freight car and train is an intriguing way to help students identify and model basic CAD designs, duplicate them and assemble them into larger structures. Such projects could always be customized for higher grades or for university level classes. In an engineering classroom, students have the opportunity to design, create and build bridge structures, so that all the individual structures could fit together as one whole 25 cm bridge capable of holding a 5 kg mass.

Thingiverse's customizer app is a wonderful resource for many 3D projects in various classrooms and different structures could be created at will based on student imagination, as is seen in the Snowflake Machine project in the Arts classroom [13]. Also, class resources should include the 3D printer projects on *Edutopia*, *Thingiverse*, *Shapeways*, *Sculpteo*, *3DPrint.com* etc. The website http://www.3ders.org is also a good resource for 3D printing technology, materials, and applications.

4 ORIENTING STUDENTS TO REAL-LIFE 3D PRINTING PROJECTS

Innovative educational projects on 3D printing should include orienting students with real-life experiences about how 3D printing is used in different industries and some of the successful projects. For a course in project management, students can analyze the feasibility and nature of such real industry projects, its possible futuristic applications, logistics and viability.

Good examples of real-life robust applications for 3D printing technology include the construction of the first 3D printed metal bridge in a district of Amsterdam, the Tokyo landscape with the 3D printed 'ONE HUNDRED TOKYO' mega-map. Adidas and Parley collaborated to produce a 3D printed running shoe consisting of ocean plastic waste.

The use of 3D-printed plastics used by Walt Disney Corporation for their Printed Optics project to bring low-voltage cool LED bulb illumination directly to their displays to make toys more interactive and responsive to children. Digital design-based 3D printed custom-made parts (e.g., auto parts or jewelry designs) have the potential to replace traditional manufacturing, because custom-made low demand or rare design product master copies are expensive to maintain in physical forms. Moreover, innovations in digital designs can be handled with short notice, and for products or parts that are no longer in use, use of digital design for instant manufacturing should mean there is no need to maintain the design copy as inventory. Such cost-effective production creates massive openings for local business. Making prosthetic limbs and arms locally, and other artificial body parts will revolutionalise healthcare. Precision is extremely important for 3D printing in the medical field, and increasingly, 3D printed models are being used for surgical planning. Developing prosthetic limbs for amputees in a war zone hospital can change the way we think about injury and rehabilitation. The ability to mass produce 3D- printed housing infrastructures in remote corners of Africa, South America or South Asia to construct ready-made low-cost customized shelters for major catastrophic zones will improve administrative efficiency related to e-governance. NASA's project on making 3D printed foods locally in the space from powdered basic materials that can be emulsified into pastes using only water is a step forward towards creating an alternative human habitat. There could be plenty of other 3D-printed projects such as creating small artifacts (toys, accessories etc.), mobile phone covers, small tools etc., which are reasonable and modest in nature, but creates a tremendous potential for local business to develop. With the decreasing cost of 3D printers and diffusion of 3G/4G network connectivity, technical communication pedagogy can also focus on the potentials of 3D Printing in the remote corners of Africa, South America or South Asia. Can such a system create a new manufacturing model and a low-cost flexible system that will offset the deficits in traditional manufacturing resulting from lack of roads, transportation, logistics, finance etc.? There are numerous other examples that could be taught and analyzed in the classroom before actual hands-on projects are initiated in a classroom setting.

This article has discussed applications of 3D printing technology that might be implemented in classroom settings for a variety of disciplines. However, there are some areas of study such as economics where the focus is not always on the processes related to 3D printing a product in the classroom. Rather, the idea is to understand how a socio-economic model of technology adoption as in the case with 3D printing can be sustained long term, including its economic and organizational implications.

5 THE ECONOMICS & SOCIOLOGY OF 3D PRINTING: THE PEDAGOGY

There are various relevant topics that might be taught in an economics or sociology classroom exclusively focused on 3D printing. An essential economic issue in the 3D printing industry is the fact that the price per unit produced is higher than traditional manufacturing, but the tooling cost is zero

[14]. Conerly [14] explains that for large production runs, traditional manufacturing will cost less per unit produced. However, the fixed expense in the industry including the high set-up and tooling costs makes it more expensive in the short-run for traditional manufacturing. Thus, when differentiating between production and productivity, the time to 3D-print a specific project is much less when compared to the tooling time in traditional manufacturing, but once the tooling process is in place, production runs are faster in a traditional set up.

Research by Weller et al., [15] argued that in 3D printing, a customized product could be made without incurring any cost penalties associated with tools and molds as in the case of traditional manufacturing. 3D printing also reduces the cost of assembly. It would be interesting for students to learn how such a 3D printing scenario will affect market structures from an operations management perspective. One of the fundamental outcomes of research is the proposal that in a monopoly, the adoption of 3D printing allows a firm to generate profit by capturing consumer surplus when flexibly producing customized products. In competitive 3D printing markets, the low barriers to entry results in lower consumer prices and serving multiple markets at the same time, thereby increasing demand [15].

Further analysis puts forward the argument that with customized and need-based local manufacturing in the 3D printing industry, the shipping expenses from the point of manufacture to the retail stores and the cost for maintaining inventory is reduced, making 3D printing a profitable option. A cost-benefit analysis, opportunity cost analysis and economies of scale are appropriate fundamental economic concepts that could be taught in an industrial economics classroom, besides other relevant models in industrial and general economics. A study of the firms, industries and markets, including multinational giants such as Wal-Mart and Tesco in the context of 3D printing offer interesting perspectives that students can investigate. An interesting perspective in an industrial economics classroom in the context of 3D printing would be to investigate whether a market is competitive, whether regulation is needed and the form it should take.

In order to understand the economics of 3D printing, a total cost perspective is a necessary field of study. This has been mentioned in a joint report of the University of Nottingham, SAID business school, University of Oxford and D2W. This report mentioned that we need a detailed understanding of the key variables that situates and establishes the business case of additive manufacturing model such as with 3D printing. A cost model to 3D printing is a fundamental precursor to defining viable business cases for novel, as well as redistributed, manufacturing applications.

A 3D printing classroom based on the understanding of economics and business models and trends should focus on articles such as Sedghi and Hall [16]. They argued that 3D printing would have a bigger economic impact than the Internet. This is because 3D printing represents an extraordinary technological shift and will likely change everything that we do and how we do it. An article by Krassenstein [17] argued that the capacity of the 3D printing industry goes much beyond the manufacturing sector. However, Krassenstein states that in order to match the estimated economic impact of the Internet, 3D printing would need to rise to $3-6 trillion. Thus, he concluded that a 100000% increase in the 3D printing adoption rate would be required to match the effects that the Internet has had. This suggest that consideration of the technology adoption lifecycle model would help students understand the adoption of 3D printing within various economies. We need an innovative technology adoption approach in a resource-constrained business environment [18]. A reasonable goal thus is to aim for sustainable business models with a customer-friendly industrial environment [19].

When introducing the use of 3D printing technology in a given environment, it is important to teach students the extent to which the technology could be adopted in a society, its acceptability, type of potential consumers, and the market where 3D printing is to be used for mass manufacturing. This understanding will be crucial to how students develop project management skills, propose business ideas and their ability to critically analyze the market.

Diffusion of innovations is a model that seeks to explain how, why and at what rate new ideas and technology spread [20]. Diffusion is the process by which innovation in a society is communicated to its members. Roger proposed that any new idea is communicated mostly through these four channels – (1) the innovation itself (2) communication channels (3) time and (4) the social system. The *technology adoption lifecycle model* is a sociological model that maps the adoption and acceptance of a product based on user characteristics including demographics of the adopter group [21]. This model identified technology adopters into several groups. Innovators are more educated, have large farms and are willing to take risk. Early adopters are younger, educated and willing to take risk and experiment with a technology. Early majority are more conservative, but open to new ideas with reasonable affordability, favor discussion and influence others. Late majority users will only adopt a technology after it is already accepted in a market on a large scale. Laggards are least educated, very conservative with small capital and unlikely to invest in a technology. When 3D printing is introduced in a developing market or a market where economic revitalization is the focus, such audience analysis is absolutely paramount.

Researchers have argued that in a number of industries, long periods of incremental improvement tend to be interrupted by short periods of radical innovation. This is referred to as the punctuated equilibrium phenomenon [22] and is well known in the management literature. In a 3D printing-based course, an important content-based investigation could focus on students exploring the question of what drives the interplay between the two: when is incremental innovation dominant, and when radical changes in technology takes over? Abernathy and Utterback [23] pointed out that industries often go through cycles of incremental innovations, punctuated by short periods of radical change. One possible reason for this is the necessary initial uncertainty reduction about a new technology, both for the providers and for the users. This leads to some experimentation and uncertainty for a period before the technology or its adoption in a context is better understood, and then an era of refinement takes over slowly ([24]; [25]).

Adoption of 3D printing as a pedagogical tool in economics and management becomes important for other logistical and cultural reasons. A sociology, management or intercultural communication class can focus on how different cultures adopt different styles in how they promote innovation and technology adoption such as 3D printing, as is often understood from the perspective of western style of management. US and the west have a strong start-up culture where students, or individuals could generate ideas and depending on its mass appeal, it can develop, in spite of the considerable amount of risk involved with a new technology. However, in an Asian collectivist context, innovation works top-down in large corporations based on a consensus building process which in turn minimizes the risk factor. The Japanese corporate culture is focused on predictability, low risk, and step-by-step improvement [26]. Levinthal [27] identified this as the slow pace of technological change based on gradualism and punctuation.

6 CONTENT AREAS IN TEACHING MANAGEMENT WITH 3D PRINTING

The management literature has a lot to offer when learning about the impact of 3D printing in the market and this could be part of a management classroom. The management literature is increasingly focused on the impact of 3D printing technology on business model innovation. Such literature investigated the changes brought about by 3D printing technologies to the business model components, including the changing nature of business model innovation, and adaptive business models through a rapid prototyping paradigm [28]. A September 2015 article published in *Information Age* by Prime [29] summed up the management perspectives in the 3D printing-based industries. An important pedagogical content dealing with 3D printing is the discussion about the reduced time spent on processes that can have huge cost and efficiency benefits. The flexibility to have more design iterations, the ability to avoid errors at the production tooling stage, and a tighter design verification process results in a better finished product. Other project-related advantages with 3D printing are how it boosts communication between staff and clients. Using a realistic physical 3D model has much more impact and provides more information at the planning and design stage as compared to computer-generated images. With 3D printing, instant creation of very customized products creates a personal rapport with the customers. 3D printing processes results in fewer mistakes during all phases of product development, mistakes could be rectified in-house, and products can be tested before it goes out to the clients. There are many other dimensions to how 3D printing could be used towards industrial efficiency and productivity. However, with 3D printing reverse engineering is possible as well, and that means a loss of billions in intellectual property. Competitors will be able to reverse engineer products far more easily without tooling expenses, and that will make it more difficult to ensure that customers are buying genuine parts and the products are under warranty.

There is a lot of scope for innovation in the 3D printing industry and how market demand is analyzed and utilized. Most of the 3D printing startup companies such as *Formlabs* and *MakerBot* has targeted customers. However, HP instead has focused on the industrial market that it sees has a larger demand to create prototypes for industrial production [30]. Onno Ponfoort [31] has extensively discussed the successful business models for 3D printing in his book. The author talked about the market requirements including the consumer market and the business market, the industry specifics, production of tooling and parts, how to join this growing industry, and the future of 3D printing. Petrick and Simpson [32] argued how 3D printing disrupts manufacturing and how this *Economies of One* create new rules of competition.

7 TEACHING TECHNICAL WRITING IN A 3D PRINTING CONTEXT

In a technical writing-based language course, students are often asked to write about procedures in a given work context, and focus on the writing context exclusively, often ignoring the fact that technical writing should also include argumentation, critical reasoning and content analysis. In the context of 3D printing, we need to understand that the technology is new, its application in the context of education especially for language learning is still exploratory, and so concerned parties could question its use as a pedagogical genre. Thus, similar to technology diffusion such as with 3D printing for mass manufacturing, pedagogical diffusion - 3D printing as a tool for language learning, should also be researched.

The technical writing coursework in English as foreign language (EFL) taught to computer science and engineering majors for example, should not focus exclusively on the mechanics of grammar and writing. Rather, an exemplary idea could be to teach both content about the socio-cultural and socio-economic dimensions of adopting a technology such as 3D printing, and also the software-based processes leading up to 3D printing in a collaborative classroom-learning environment, besides writing. This type of course could be replicated and customized for both native and non-native writing contexts. Besides project management and sociocultural and socioeconomic factors, students will learn about the seamless flow in manufacturing and entrepreneurship that connects writing about their first-hand in-class experience of handling 3D design software such as *BuildwithChrome*, *Autodesk*, *Tinkercad*, 3D scanners such as *Sense* and *iSense*, collaborative documentation such as *Google Drive*, brainstorming with IHMC concept mapping software, *Cubify* design feeds and slicing software, and online design repositories such as *Thingiverse*, *Shapeways* etc. Following are examples of EFL technical writing courses (taught by the authors of this paper) titled *Technical Communication with LEGO and 3D Printing* with in-class procedures as follows:

- Design prototyping with LEGO
- Use of CMAP software apps with iPad
- Developing Google Sites / Sitebuilder webpages based on design from LEGO prototyping
- 3D scanning with Sense and iSense scanners
- Use of 3D software to replicate the scanned images
- Upload and research design on *Thingiverse, Shapeways, Sculpteo*, and *Cubify* etc.
- Save and slice the scanned images as .stl file
- 3D print the images with Cubify printer as and when necessary
- Use Google Drive continuously throughout the quarter to write collaboratively – author feasibility, recommendation, lab and design reports.

So, in a task-based technical writing classroom, we will try to adopt the following sequence of activities.

1. Students read about a project about a product design
2. Do their own Google scholar research about the project and how to design an innovative product
3. Write a recommendation and feasibility report about the project idea and its validity in the context of use (consider various sociocultural and socioeconomic models discussed earlier)
4. Make a physical LEGO prototype of a design
5. Use various CAD software to develop on the design done with physical LEGO blocks
6. Co-author continuously Google drive-based design reports
7. Co-author a Google Sites / Sitebuilder webpage in a group with separate roles for group members, explaining the design process (analysis, concept and synthesis) and product sustainability (materials, construction, functions, appearance and social/environmental factors)
8. 3D scan the LEGO product and write procedural instructions about the 3D scanning process

9 3D print the object

10 Prepare final design report

11 Prepare recommendation report explaining possible future development and current limitations including suggestions for improvement

12 Prepare the final feasibility report based on Step 7.

13 Design and deliver a persuasive technical presentation arguing to the “management” (class teacher) why the product is unique and should be adopted.

14 A digital storytelling video about the 3D printing process (optional)

The authors believe that such a course, as the one described above could be successful in learning environments where there is sufficient interest and motivation to work on individual ideas and concepts. In this pedagogical framework, we have tried to include both individual thinking and group-work, besides writing. The concept of developing individual design and documents is geared towards developing a start-up culture where students feel motivated to work individually, communicate in groups and share ideas globally in online forums such as *Facebook* and *Pinterest* and get adequate feedback. Similar courses have already been offered at the graduate and undergraduate level in this university that are focused on LEGO prototyping and design, and technical writing leading to 3D printing. But the course as discussed above, teaches both socioeconomic perspectives and design fundamentals using 3D printing and technical writing.

Initial observations with an existing course (*Writing and Design with LEGO*) at the undergraduate level have shown that students were able to complete LEGO prototyping using physical LEGO blocks and 3D design software such as *Autodesk 123D Design and Make, Tinkercad* and *BuildwithChrome*. Further, student groups could successfully write about the product design with some English proficiency, although there is a lot of room for improvement when it came to document organization, website design and content research for reporting. Further, data suggested that there was much room for improvement when it came to critical reasoning and documenting a procedure. But, students could satisfy the basic requirements such as forming an argument based on a product design, writing about the processes they completed, analyzing the various product dimensions etc. As observed from the graduate course (*Technical Writing in Software Engineering*), students demonstrated much more expertise when it came to understanding the complexity of the assignment, and executing the sequential steps. In this technical writing course, students did extensive 3D scanning based on design prototypes with 3D software same as in the undergraduate course, and wrote about the limitations of using iSense versus the Sense scanners. Further, students were able to complete extensive research on the feasibility of a product design, develop product design dimensions, and finally following all the experiments along the way, they were able to slice the .stl file and 3D print it successfully using the Cubify printer. Students could also write feasibility reports based on their own design and compare it with design from Thingiverse. Throughout the course, students successfully used Google Drive to take notes, write about the process sequences, review the design, conduct short experiments with 3D scanners based on different product shapes, make comments on the design, its improvement, design specifications etc. As part of this course, students received guidance on how to work in groups, communicate with group members, follow design rubrics, and make oral presentations in English etc.

8 CONCLUSIONS

There is a definite need to develop intellectual capital to advance innovation and entrepreneurial capacity and sustain the knowledge economy [33]. Just being able to read about some of the 3D printing initiatives in the classroom, including the projects in *Thingiverse* will allow students to widen their imagination and scope for critical thinking. Readings and follow-up analysis on topics related to the 3D student curriculum designed by MakerBot Industries, to interesting new projects from *Thingiverse* capture student interest, stimulate interaction during classroom, create tangible aids, facilitates hands-on learning through 3D models and most importantly, foster a problem-solving mindset and improves reasoning power.

The proposal and coursework discussed above could be largely adapted in an effort to build intellectual capital for a generation whose dependence on 3D printing might revolutionalise local manufacturing and help shape a smart community in both developing and developed economy context. Intellectual capital comprises of both organizational capital and human capital. 3D printing initiatives need both. The proposed technical writing and language coursework as discussed is an initiative to teach task-based functional English language in a non-native context through efforts to build project management capabilities and technological skills. Such multicentric pedagogical structures should have the potential to not only cultivate an entrepreneurial mindset that ultimately leads to development of industries, but also may help to educate students who are able to communicate and mediate with the outside world in the local language and English, and innovate on product design and manufacturing in a way that is essential for community and infrastructure development. Local 3D printing initiative is a wonderful opportunity to contribute locally and make an impact globally. We should see 3D printing as a system complementing traditional manufacturing with shorter planning, design and execution [34], but challenges remain for the future. To have a good *3D Printing for Education* program at the university level, the teaching staff must have sound knowledge about the technology, should have enough experience to think about the teaching approaches, and enough non-contact time to plan the most effective way to use the printers and other related software. Further, good technical support both from the manufacturers and internal university staff is necessary to train the teachers. Using 3D printers in the classroom for pedagogical purposes is and should be a team effort.

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