Manufacturing Design Thinkers in Higher Education Institutions: The Use of Design Thinking Curriculum in the Education Landscape

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***Abstract*—Design Thinking is commonly used by businesses as a mindset and approach for problem-solving, learning, and collaboration. Such methodology is a beneficial addition to the pedagogy selections used in the education landscape especially to fields that build products (e.g., computer systems) requiring significant considerations to its functional designs. In this study, the use of Design Thinking Curriculum was explored in Higher Education Institutions particularly on Information Technology and Computer Science programs to determine its impact to the skills and abilities of future computing professionals. To do this, a self-assessment scale that comprises of 31 measurement items divided into seven dimensions was given to computing students. Findings establish that computing students enrolled in a Design Thinking Curriculum have significantly improved in all scales compared to those who are not. Therefore, this study validates the application of Design Thinking Curriculum in education as an approach to encourage innovation in the computing field.**

Keywords— Design Thinking, Innovation, Human-Centered Design, Computer Science, Information Technology,

I. INTRODUCTION

Design Thinking (DT) is described as a human-centered problem solving method [1] that usually leads to innovative solutions in seemingly new ways [2]. As a problem-solving approach, creatives employed DT in everyday-life problems and those "wicked problems" as discussed by Buchanan [3]. Because of its applicability to any problem requiring solution, the term DT is becoming ubiquitous. In fact, DT has evolved over the past few decades expanding its presence into various areas in life such as business [4], engineering [5], healthcare [6], education [7], and more. However, the meaning of *design* still has a multitude of interpretation depending on the field it is being utilized. For instance, the use of design in a business management context is often pondered as innovation while it can be sometimes a routine taken for granted in Engineering [8]. On the other hand, it is a theory-based intervention when utilized in the education settings [9]. Nonetheless, DT is a skill needed by everyone to succeed in today's technological world [10]. Moreover, students will be prepared with difficult issues requiring complex solutions when molded as a design thinker. To attain this, intriguing tasks should be incorporated into the classroom that provides many opportunities to be creative and apply design processes [11]. In short, to be a design thinker, a school should be converted into a haven where learners are not molded to get high scores in standardized assessments but to equip them with skill sets that will enable them succeed both within and outside of the institution. Such practice requires the installation of a technique to increase students' proficiency.

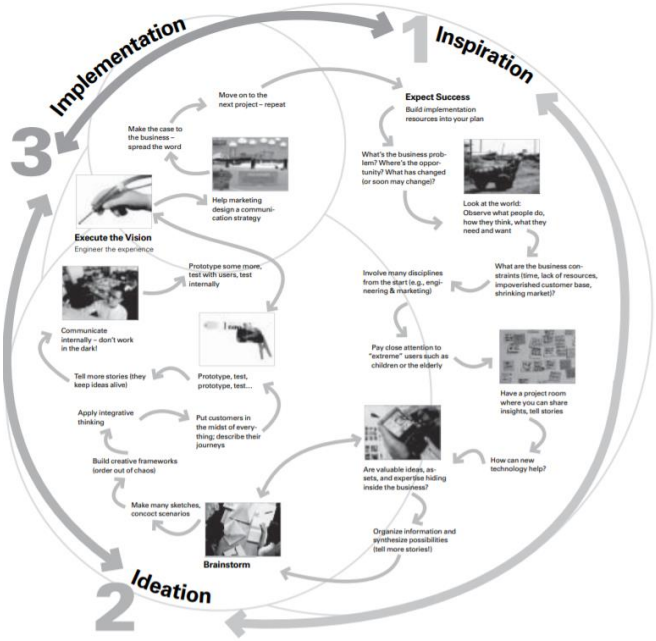

Fig. 1. Three-Step Design Thinking Approach [1]

In recent years, Higher Education Institutions (HEIs) in the Philippines have actively complied and implemented the important directives and requirements of the Commission on Higher Education (CHED) to cultivate innovative talents as well as entrepreneurial skills to keep up with the searing pace of change. Among these requirements for entrepreneurship education is the development of quality innovation courses – the likes of DT in integrated design education inspired by a curriculum from Stanford University [12]. Originating from designers' creative tools, DT has been proven in the business field to effectively innovate thinking and methods to solve difficult problems. Cross [13] pointed out that the success of modern business requires the analytical capabilities brought by traditional business education, as well as creative and DT techniques. In practice, people have a different understanding of connotation [13-15], and scholars often explore DT through qualitative research methods [4, 16] (e.g., theoretical analysis, case studies). Although DT is starting to capture the attention of the education landscape, its evaluation on how to produce design thinkers especially in the field of Computer Science and Information Technology has not yet been explored. In this study, the use of DT as a mindset to solve wicked problems in a form of workshop was assessed under DT curriculum-based course design and how it affects students in various scales.

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II. Research Review

A. Connotation and Characteristics of Design Thinking

DT is a perspective to look at problems and a methodology of thinking to find innovative solutions to problems we face. There are many ways to practice DT, and their characteristics are also different (See Table 1). A breadth of research believes that DT is inspired by the thinking and the way of working is a way of thinking that leads to a new way of life. It can bring breakthroughs to wicked problems in different fields. In recent years, many scholars have conducted theoretical research and case studies on design thinking under different backgrounds. The different characteristics of DT is summarized below.

TABLE I. Different Characteristics of Design Thinking

Source	Design Thinking Characteristics
Brown [1]	Empathy, Integrated Thinking, Optimism, Experimentalism, Collaboration
Blizzard [17]	Collaboration, Experimentalism, Optimism, Feedback Seeker, Integrated Thinking
Cankurtaran [18]	Retrospective Reasoning, Iterative Thinking and Experiment, Holistic Perspective, People-Oriented
Carlgren [19]	User-Centric, Problem-Oriented, Visualization, Experimentalism, Diversity
Micheli et al. [20]	Induced Reasoning, Balance, Cooperation, Design Tools, Innovation, Problem Solving, Systematic View, Tolerating Failure, User-centricity

Although scholars have narrated different characteristics of DT, they also have some common points. Problem-oriented is the primary characteristic of DT. It solves complex problem motivated by imagination, curiosity and creativity to explore and develop innovative products [15]. In addition, as a human-centered design process, DT is people-oriented. It accentuates human needs and places preferences at the center of the design process, not just a product or a service. It is also emphasizes the importance of collaboration by creating environments that differentiate breakthrough insights and solutions [21]. With a goal to solve wicked problems, optimism is also warranted. In traditional analytical thinking, failure is not acceptable; in DT, however, failure is a way of learning that requires an action to obtain knowledge. DT is based on a basic belief that everyone can creating change, no matter how big the problem is, how short the time is, or how limited the budget is. Design can also be a satisfying process through its visualization characteristic. Visualization is not just to visualize the concept, but to make any idea tangible. DT has different visual tools can be used in the scene to improve the novelty and value of the generated ideas. Retroactive reasoning is also another feature of DT. It offers backward thinking which is different from deductive and inductive reasoning inferencing to multiple observations that involves a possibility of existence, challenge what exists, ask "what if" questions. The last feature of DT is innovation and often described as a creative, subjective, and emotional choice that requires participants to challenge and reconstruct the problem. Instead of simply trying to solve a problem, this focuses on stimulating different innovative ideas to a certain extent. In recent years, DT has gradually become a non-design field and more and more fields are starting to see its potential particularly on its innovation capabilities. In summary, this review concludes that there are seven main characteristics of DT based from various research and scholar such as problem-oriented, collaboration, optimism, visualization, retroactive reasoning, people-oriented, and innovation.

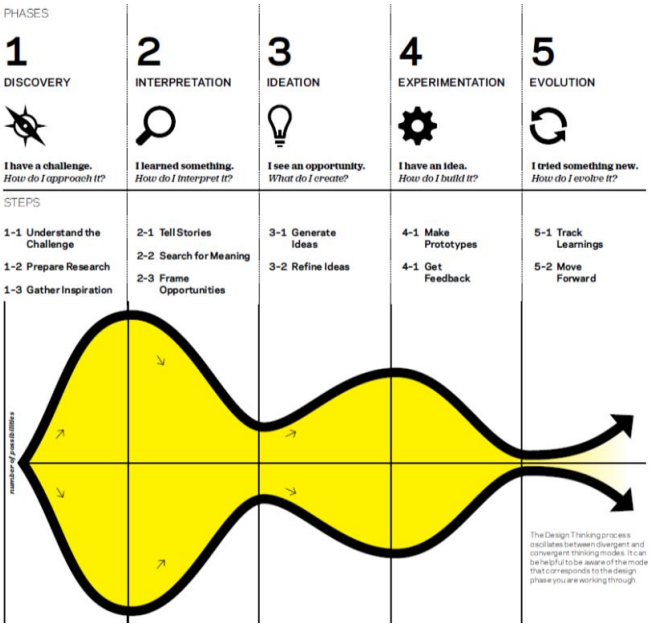

Fig. 2. Design Thinking Process for Educators [22]

B. Design Thinking Process

The most popular DT process is comprises of five stages: empathize, define, ideate, prototype, and test. The first step is to understand the perspective of others, and discover user intentions through various ethnographic research techniques, such as participant observation and journey mapping. After a series of empathetic methodologies, the findings from this step will be translated into the actual needs of the user and forms a description of the solution to the problem faced by the user as well. The third stage is the creation of ideas. It mainly collects the ideas of relevant people. Regardless of the quality of the ideas and the feasibility, each participants are encouraged to submit as much as many ideas. Then, the next DT stage is prototyping where ideas are expressed through visual tools, because design prototypes are tangible hand-made products that help to understand, learn and communicate concepts and ideas. Lastly, testing, is where DT practitioners will find out what is feasible, collect feedback to modify the prototype, and iterate processes to find prototypes that better meet user needs. In this process, a designer first sees the concept of the problem that needs to be solved, then draws the relationship between the ideas to solve the problem, and finally views the drawn content as information for further design work. The whole process emphasizes observation, collaboration, rapid learning, idea visualization, rapid concept prototyping and parallel business analysis involves synthesizing a variety of, often radically different, ideas into multiple reasonable solutions. When DT is applied in education, IDEO has recommended a quite different process [22]. As shown on Figure 2, it includes a five-step process as well but with different approach such as discovery, interpretation, ideation, experimentation, and lastly evolution. Nevertheless, it still aims the same output.

C. Research on Design Thinking in Education

DT has a positive impact on interdisciplinary education in the 21st century as it provides students with effective responses to the future with an ever-changing challenge tool [7, 12, 14, 16]. Some scholars have explored the impact of integrating DT into classroom teaching. In digital fabrication [23], it was found out that students were provided with an understanding of the creative and complex process in the subjects through

the aid of DT. In Engineering [24], freshmen who projected to have an engineering major significantly score higher than senior engineering students, as well as better than feedback seeking and experimentalism. Furthermore, a study about the implementation of DT in Science, Technology, Engineering, and Mathematics (STEM) curricula reveals a positive impact on student perceptions about the program [25]. In addition, a research report evaluation of the effectiveness of academic education shows that students have improved their problem-solving skills in the curriculum [26]. In other school practice, DT teaching improved students' ability to learn core subjects, cultivated social skills, and how to work in groups [27].

III. Design Thinking Course Design

As an innovative method that has been proven in practice, DT succeeds if its three elements are properly integrated. As such, the Design Thinking Course (DTC) implemented in the institution includes *process*, *space*, and *team* [28]. Moreover, a Design Thinking Summit was conducted before the end of the term where students from different programs and sections gathered to produce innovative solutions to a given problem.

Fig. 3. Brainstorming Session to Develop Innovative Solutions

A. Design of Three Elements of Design Thinking

1) Five-step process of iterative evolution

Challenges to be addressed by the course are raised by the teacher. The overall organization of the course is gradually promoted by the five-step process of design thinking, with key deliverables per each stage (e.g. customer journey maps, How Might We [HMW], empathy maps, customer portraits and Point of Views [POVs], brainstorming, Lego prototypes, test feedbacks, etc.) as the basis for the course assessment. Specific classroom organization consists of opening videos, lectures on the tool process, thinking training games, practice and usage of various innovative tools. Then, as part of active learning pedagogy, there is a production teacher feedback, and other forms of interactive presentations and activities.

2) Flexible free variable space

DTC was conducted in a dedicated classroom designed to be a flexible space to give free ambience for creativity as well as innovation. There were three large walls decorated as glass whiteboards, and stage results were recorded and displayed. Seats can be freely moved and easily combined with others to foster collaboration. The classroom can have a background music to stimulate creativity and relaxing mood. At the same time, materials such as big white paper, colored pencils, post-it notes, marker sticky tape, dot stickers, Lego bricks, scratch papers, and pencils are also available for basic course props.

3) Cross-border team working together

The DT team exhibits diversity in terms of backgrounds, knowledge, and skills to generate intense brain shock, and achieve a lot of unprecedented ideas. Students in the courses also studied in small groups to prevent the usual classroom hindrances. When grouping, students emphasize the diversity of the group in terms of gender, forte, and preferences.

B. Course Design Practices and Examples

Table 2 shows the seven characteristics of DT which are presented in different forms in the curriculum. Part of the link is in hidden lessons and process content includes features such as "people-oriented" that are implicit in user insights. Further, “innovation” was based on the results produced step-by-step in the classroom in a form of group activities then combined into a tangible output. The "optimistic" feature was reflected in the use of the HMW tool. There was also a ring of festival strengthened through small games and exercises in the course, such as the practice of stick figures for visual feature, team display and evaluation. Price strengthens the characteristic of "collaboration" and the encouragement to work as one. It is important to note that all activities were designed in order to comply with and practice the different characteristics of DT.

TABLE II. Different Characteristics of Design Thinking

DT Features	Related Course Design Links
Problem-oriented	Courses start with problems; innovative solutions focus on problem solving
People-oriented	User insights; use of empathy maps and customer portraits
Cooperation	Course organization in groups: team presentation
Optimism	Explanations Embracing Failure: Explaining the Meaning of HMW Tools
Visualization	Stick figure exercises; creative visual display; stage results display wall
Retroactive Reasoning	Use of 5W tools
Creativity	Innovation results in the classroom step by step procedures

IV. Empirical Analysis of Curriculum Effect

A. Scale Design and Sample Selection

Drawing on the research results of various papers on DT characteristics [1, 17-20], this study puts together a validated self-assessment scale that includes 31 measurement items in seven dimensions. Respondents were enlisted from HEIs and grouped into two: with and without DTC. Students with DTC answered the assessment after the DT Summit and students without DTC gave their assessment in the same timeline. This questionnaire intends to explore and understand the impact of DTC to future computing professionals, and how the addition of DT (as a mindset) in the course affects them.

B. Reliability, Validity, and Normal Distribution Test

To measure internal consistency of the self-assessment questionnaire, Cronbach’s Alpha was used. The overall result of alpha coefficient was 0.98. The KMO value of the sample was 0.959, and the chi-square value of the Bartlett Sphericity test was 3276.747 ($p = 0.000$, <0.05). This means that the scale achieved a high reliability and validity. Further, the skewness coefficient (<1.0) and kurtosis coefficient (<2.0) of the seven dimensions of DT are relatively small. The standard deviation of skewness is 0.230, and the quasi error is 0.457, which then indicates that the collected data using this questionnaire is normally distributed and suitable for difference analysis.

Fig. 4. Presentation of Innovative Solutions Based on a Five-Step Process

C. *Difference Anaylsis for Implementing DTC*

Using independent sample T-test in SPSS, the significant difference between two groups were analyzed. Based from the results as shown on the Table below, there are significant differences in all seven dimensions of DT between students in group A and those in group B. ($p = 0.000 < 0.05$). The mean value of seven dimensions such as problem-oriented, people-oriented, optimism, innovation, retroactive reasoning, collaboration, and visualization, were all higher in Group A (mean value = 3.79). At the same time, it can also be seen that the mean difference of collaboration (3.98) is the highest (from Group A) while people-oriented (1.19) got the lowest score (from Group B) among all dimensions. These results should get the attention of stakeholders (from management to computing professors) as the implementation of DT, or lack thereof, in the programs has a significant effect. First of all, a computing professional should be problem-oriented since the list of their projects in the industry are all about making the best possible solution through technological advancements. A computing professional who is not a design thinker could have a reduced ability to collaborate with their teammates. In an exploratory study that focuses on game-based activity in a computing program [29], students performed well when they can collaborate with their classmates. This happens because of the opportunity to discuss the lesson with peers, learn from others, and produce a viable solution that might not have been possible to create on their own [30]. Therefore, with a DTC installed in the program, there was a supplementary process that enhances students' skills necessary for their courses in school, and at the same time, applicable in their career.

TABLE III. DIFFERENCE ANALYSIS RESULTS OF EACH DIMENSION

Dimension	Group	Mean	Standard Deviation	Levene Test	p-value
Problem-oriented	A	3.76	0.395	0.482	0.000
	B	2.14	0.358		
People oriented	A	3.77	0.443	0.004	0.000
	B	1.19	0.296		
Collaboration	A	3.98	0.406	0.011	0.000
	B	2.00	0.293		
Optimism	A	3.83	0.417	0.327	0.000
	B	2.00	0.336		
Visualization	A	3.89	0.583	0.399	0.000
	B	1.82	0.485		
Retroactive reasoning	A	3.75	0.446	0.111	0.000
	B	2.02	0.331		
Creativity	A	3.53	0.452	0.331	0.000
	B	3.52	0.198		

Fig. 5. Mobile Application to Spread Health Awareness

Fig. 6. Game-Based Tutorial for Supplementing Programming Course

V. CONCLUSION

In this study, the implementation of DT in the Information Technology and Computer Science programs through DTC was explored. The analysis was performed through the self-assessment scale with seven dimensions of DT. It is important to note that the DTC used was in its infancy stage – the first syllabus version – and will be revised every trimester with the emergence of high quality papers. Nevertheless, this study revealed that students who did not participated in a DTC have significantly lower score in all dimensions. Therefore, a DTC should be implemented as part of the curriculum of Computer Science and Information Technology since both programs are all about building products (e.g., computer systems and other devices [31]) that solve everyday problems. With a DTC as part of their program, college students will be able to develop their skills in creatively solving problems even in non-design areas. It is now in the hands of educational leaders to initiate a program that could hone 21st century skills (e.g., DT) that will prepare computing students not only for college but also in their future career. With these necessary skills, computing students can be transformed into a design thinker who is able to visualize systemic solutions, has interpersonal skills that allows them to communicate with others, and the continuous consideration on how a solution serves human needs.

REFERENCES

[1] T. Brown, "Design Thinking," Harvard Business Review, vol. 86, no. 6, pp. 84-92, 2008.

[2] L. Kimbell, "Rethinking Design Thinking: Part I," Design and Culture, vol. 3, no. 3, pp. 285-306, 2011/11/01 2011.

[3] R. Buchanan, "Wicked Problems in Design Thinking," Design Issues, vol. 8, no. 2, pp. 5-21, 1992.

[4] Z. Howard, "Understanding design thinking in practice: a qualitative study of design led professionals working with large organisations," Swinburne University of Technology, Melbourne (AUS), 2015.

[5] C. L. Dym, A. M. Agogino, O. Eris, D. D. Frey, and L. J. Leifer, "Engineering Design Thinking, Teaching, and Learning," Journal of Engineering Education, vol. 94, no. 1, pp. 103-120, 2005.

[6] M. Altman, T. Huang, and J. J. P. C. D. Breland, "Design Thinking in Health Care," vol. 15, 2018.

[7] S. Panke, "Design Thinking in Education: Perspectives, Opportunities and Challenges," Open Education Studies, vol. 1, no. 1, 2019.

[8] U. Johansson-Sköldberg, J. Woodilla, and M. Çetinkaya, "Design Thinking: Past, Present and Possible Futures," Creativity and Innovation Management, https://doi.org/10.1111/caim.12023 vol. 22, no. 2, pp. 121-146, 2013/06/01 2013.

[9] P. Cobb, J. Confrey, A. diSessa, R. Lehrer, and L. Schauble, "Design Experiments in Educational Research," Educational Researcher, vol. 32, no. 1, pp. 9-13, 2003/01/01 2003.

[10] R. Razzouk and V. Shute, "What Is Design Thinking and Why Is It Important?," Review of Educational Research, vol. 82, no. 3, 2012.

[11] R. Eisentraut, "Styles of problem solving and their influence on the design process," Design Studies, vol. 20, no. 5, pp. 431-437, 1999.

[12] J.-C. Tu, L.-X. Liu, and K.-Y. Wu, "Study on the Learning Effectiveness of Stanford Design Thinking in Integrated Design Education," Sustainability, vol. 10, no. 8, 2018.

[13] N. Cross, Design Thinking: Understanding How Designers Think and Work. Berg Publishers, 2011.

[14] D. Dunne and R. Martin, "Design thinking and how it will change management education: An interview and discussion," Academy of Management Learning & Education, vol. 5, no. 4, pp. 512–523, 2006.

[15] C. M. Piotrowski, Problem Solving and Critical Thinking for Designers. Hoboken, NJ: Wiley, 2011.

[16] J. E. McLaughlin, M. D. Wolcott, D. Hubbard, K. Umstead, and T. R. Rider, "A qualitative review of the design thinking framework in health professions education," BMC Medical Education, 2019.

[17] J. L. Blizzard, L. Klotz, G. Potvin, Z. Hazari, J. Cribbs, and A. J. D. S. Godwin, "Using survey questions to identify and learn more about those who exhibit design thinking traits," vol. 38, pp. 92-110, 2015.

[18] P. Cankurtaran and M. B. Beverland, "Using design thinking to respond to crises: B2B lessons from the 2020 COVID-19 pandemic," Industrial Marketing Management, vol. 88, pp. 255-260, 2020.

[19] L. Carlgren, M. Elmquist, and I. Rauth, "Design Thinking: Exploring Values and Effects from an Innovation Capability Perspective," The Design Journal, vol. 17, no. 3, pp. 403-423, 2014/09/01 2014.

[20] P. Micheli, S. J. S. Wilner, S. H. Bhatti, M. Mura, and M. B. Beverland, "Doing Design Thinking: Conceptual Review, Synthesis, and Research Agenda," Journal of Product Innovation Management, https://doi.org/10.1111/jpim.12466 vol. 36, no. 2, 2019.

[21] M. E. Porter and M. Kramer, "Creating shared value," Harvard Business Review, vol. 89, no. 1, pp. 62-77, 2011.

[22] IDEO. (2013). Design Thinking for Educators. Available: https://www.ideo.com/post/design-thinking-for-educators

[23] R. C. Smith, O. S. Iversen, and M. Hjorth, "Design thinking for digital fabrication in education," International Journal of Child-Computer Interaction, vol. 5, pp. 20-28, 2015/09/01/ 2015.

[24] E. Coleman, T. Shealy, J. Grohs, and A. Godwin, "Design thinking among first-year and senior engineering students: A cross-sectional, national study measuring perceived ability," Journal of Engineering Education, https://doi.org/10.1002/jee.20298 vol. 109, 2020.

[25] M. E. Dotson, V. Alvarez, M. Tackett, G. Asturias, I. Leon, and N. Ramanujam, "Design Thinking-Based STEM Learning: Preliminary Results on Achieving Scale and Sustainability Through the IGNITE Model," (in English), Curriculum, Instruction, and Pedagogy vol. 5, no. 14, 2020-February-25 2020.

[26] K.-C. Yu, S.-C. Fan, and K.-Y. Lin, "Enhancing Student's Problem-Solving Skills Through Context-Based Learning," International Journal of Science and Mathematics Education, vol. 13, no. 6, pp. 1377-1401, 2015/12/01 2015.

[27] Y. Li et al., "Design and Design Thinking in STEM Education," Journal for STEM Education Research, vol. 2, no. 2, 2019.

[28] R. Edart. (2016). The 3 elements to innovate with Design Thinking. Available: https://www.linkedin.com/pulse/3-elements-innovate-design-thinking-r%C3%A9mi-edart

[29] M. B. Garcia et al., "Game Development as a Pedagogical Methodology in Learning Related ICT Skills: Perspectives of Freshmen from FEU Institute of Technology," International Journal of Simulation: Systems, Science & Technology, vol. 20, no. 2, 2019.

[30] J. Chen, M. Wang, P. A. Kirschner, and C.-C. Tsai, "The Role of Collaboration, Computer Use, Learning Environments, and Supporting Strategies in CSCL: A Meta-Analysis," Review of Educational Research, vol. 88, no. 6, pp. 799-843, 2018/12/01 2018.

[31] M. L. Goh, M. B. Garcia, A. C. Lagman, J.-A. Lalata, R. M. De Angel, and H. Vicente, "A Pocket-Sized Interactive Pillbox Device: Design and Development of a Microcontroller-Based System for Medicine Intake Adherence," in International Conference on Computational Intelligence and Knowledge Economy, 2019: IEEE.