Chapter

The TIPE Model for Teaching Technology-Based Entrepreneurship

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Abstract

It is widely believed that the technology-based entrepreneurship has great potential to increase wealth and competitiveness. Researchers believe that Technology-based Entrepreneurship Education (TEE) may raise students' awareness about the technology entrepreneurship and the opportunities for technology commercialization. However, TEE has a relatively shorter history than conventional entrepreneurship education in business schools and there are fewer cases. This paper will use a revised 4W1H framework to review existing models of TEE and then present the TIPE model that has been implemented at a university in Hong Kong since 2001 for master students. Educational and policy implications are explored finally.

Keywords: Entrepreneuship education (EE), technology-based entrepreneurship education (TEE), technology transfer (TT)

1. Introduction

The first entrepreneurship course was introduced as early as in the 1940s at Harvard University. In the 1970s, entrepreneurship education began to gain more attention and many business schools started to offer one or more courses in small business or entrepreneurship. Entrepreneurship education has developed very fast across the world since the 1990s until now [1–7]. Although entrepreneurship education growing fast, technology-based entrepreneurship education for engineering students was rather later and fewer [8, 9]. In a survey of 160 academic institutions, Streeter et al. [10] found that entrepreneurship-related courses have been offered in nearly 90% of the bachelor programs in business schools while less than 40% engineering bachelor programs contain entrepreneurship courses. On research side, Bailetti [11] reviewed 93 articles on technology entrepreneurship, but none of these articles is related to technology-based entrepreneurship education (TEE).

It has been widely believed that the technology-based entrepreneurship has great potential to increase wealth and competitiveness at both national level [12, 13] and regional level [14]. Researchers believe that Technology Entrepreneurship Education (TEE) may raise students' awareness about the entrepreneurial opportunities for technology and commercialization [15]. Starting a new company (entrepreneurship) or a new business in an existing company (intrapreneurship) is the final step to commercialize a new technology via providing values to the end users.

This paper will first use the 4W1H framework by Fayolle [16] to review previous TEE models and then summarize the basic factors and TEE model as well as its

difference from market-driven entrepreneurship. The paper will then introduce the TIPE Model (Technology-Idea-Product-Enterprise) as a detailed example with a view to elaborate the 4W1H framework at the operational level. The PIPE model was implemented in a course titled Technological Innovation and Entrepreneurship for master students since 2001 in one department and now has expanded to five master programs in systems engineering, mechanical engineering, computer science, healthcare & bio-engineering and electronical engineering as an elective or core course.

2. Literature review of previous TEE models

In this section, the 4W1H framework by Fayolle [16] is used to systematically review eight previous models on TEE courses or programs in engineering schools. The 4W1H framework by Fayolle [16] contains five dimensions: i.e., "For whom" (the audience or students), "Why" (the objectives), "What" (the contents), "How" (the teaching methods) and "For which results" (the evaluation and assessment levels). Another dimension is added in this paper, i.e., "By who" (the offering schools/departments). This structure is very similar to other review papers on entrepreneurship courses or programs (e.g., [9, 17]). The structured review is illustrated in **Table 1** and elaborated below.

2.1 The audiences (whom)

The reviewed models serve either undergraduate or postgraduate students or both (graduate students in US terms in some reference such as [15]). They range from a single course, a minor program or a multi-semester program. For those undergraduate entrepreneurship programs in engineering schools, a concern is how the credits from those entrepreneurship courses can be recognized in an engineering field. Lacking space and time for elective credits in engineering degree programs is a major and common barrier to entrepreneurship courses for engineering students Standish-Kuon, [8]. This is not a big problem in the business school since entrepreneurship courses are accepted as management or management related courses. For master level courses or programs, it is not very clear whether the TEE course is a credit bearing course in a master program or an extra curriculum course (e.g., [21]).

2.2 The objectives (why)

Markham et al. [15] believe that TEE may raise their awareness about the entrepreneurial opportunities to promote technology commercialization. There are basically two types of objectives among the reviewed programs/courses, namely, a) nurturing students' generic entrepreneurial skills and enhance entrepreneurial awareness [18, 23], b) nurturing students' entrepreneurial skills and enhance entrepreneurial awareness based on new technologies. Three courses claim their objectives are launching, managing, and growing technology-based businesses which can be regarded as TEE (e.g., [15, 21]). Therefore, not all entrepreneurship programs/courses for or by engineering schools are necessarily TEE. Some course or programs offered by engineering schools can be similar to those offered at the business school except the audiences are engineering students.

2.3 The contents (what)

All entrepreneurship courses and programs offer pretty similar set of contents including creativity, innovation, opportunity identification and business plan.

Ref & country	For whom (Students) and by who (host)	Why (Objectives)	What (Contents)	How (Methods)	What result? (Assessment)
Markham et al. [15]	Engineering and management graduate students, by College of Engineering and Management, USA	Turn engineers into technology entrepreneurs by technology evaluation and commercialization (TEC)	Technology search, Product idea generation, potential analysis Commercialization strategy and business plan	Use technology startup as a pedagogical tool teach technology entrepreneurship in a 3-semester program.	Student can initiate their own technology companies after graduation or enter corporate venturing division
Kingon, et al. [18]	Two engineering entrepreneurship minor programs, by both engineering and business schools USA	create awareness among engineering students of entrepreneurial opportunities, and the business dimension of product development,	Business models, Communication, Cross functional teams, and Entrepreneurial thinking	From experience-based teaching to process-based teaching approach	Creation associated with the development of the entrepreneurial opportunity and finally a business proposal, create, rather than a new venture creation.
Collet and Wyatt [19]	A degree program for undergraduate students in biotechnology, by a Department of Biotechnology, Australia	Provide students with commercial imperatives and meet the demand of bio-industry for talents with skills in product development, business, IP, law and commercialization.	32 subjects: 19 for bio technologies, 8 for entrepreneurship, innovation and management, 1 for IP and law and 4 for project in virtual student companies.	Student self-driven, team-based learning in a virtual company environment or company based internship projects.	• Self and peer assessment of entrepreneurship project, • Industry employment and recognition of graduate capabilities.
Boocock et al. [20]	Master students in a MBA program, based on the TEC Algorithm [15]	Understanding of academic knowledge about technology based product ideas development and application of business concepts to technologies Selection	Search & ideation, assessment & analysis, commercialization strategy	n/a	From a business proposal up to a few new businesses,
Hartmann [21]	An elective course for master, PhD students and employees of a technical university, by Department of Innovation management and entrepreneurship, the Netherlands,	Connect technological research with education using patented technologies developed at the research faculties of a technical university	The technology and patent, the problems, the solutions based on the technology, the potential end users, the potential price and the alternatives in the market.	Seven four-hour sessions that combine lectures, participant-centred case studies, classroom exercises, real-life case studies, and trial presentations by interdisciplinary teams.	Cases of new technology startup

Ref & country	For whom (Students) and by who (host)	Why (Objectives)	What (Contents)	How (Methods)	What result? (Assessment)
Karim [22]	An entrepreneurship course for civil engineering students, by Department of Civil Engineering, Malaysia	To nurture the ability to venture development and leadership in energy related business, and engages in activities to enhance knowledge in their professional works.	New product development Idea generation Market research Feasibility of idea Finance Production Management Teamwork Business Marketing Management	Didactic (read/lecture) Skill building (case studies group discussions, presentations, problem solving, simulations, teamwork, projects) Discovery	Personal development, entrepreneurship and management knowledge, problem solving skills, decision making, presentation, risk taking) Career development.
Kazakeviciute et al. [9]	Undergraduate students in science, health, engineering, design, information technologies etc. (By lecturers from business school and guest speakers)	Knowledge about entrepreneurship itself, the importance of skills, values to entrepreneurial mindset and entrepreneurial skills.	Individual, team-based and business-related topics and activities, while applying the lean business model as well as the fundamentals of technology entrepreneurship.	Theory and cases, interaction sessions and monitoring sessions.	The first is based on students' evaluation of course delivery and content, the second on students' evaluation of their progress.
STVP [23]	STVP program for both undergraduate and postgraduate students, by An entrepreneurship center at the School of Engineering, USA	To learn about identifying market opportunities and assuming leadership roles in business.	A series of courses on creativity, innovation and entrepreneurial marketing, finance, strategy, and other management areas.	Conventional course, large public lecture series and intensive, year-long extracurricular programs such as the Mayfield Fellows Program	STVP produces a large and growing collection of online content and experiences for people around the world.

Table 1.
The review of previous TEE models based on the 4W1H framework [16].

However, TEE courses and programs provide unique contents on technology search and identification, new product development and intellectual property etc., which normal EE courses may not need to cover. This is perhaps the major uniqueness of TEE in terms of the content.

2.4 The method (how)

Talking about the teaching methods, the business schools have traditionally used case study method but more new methods are being adopted such as action learning, project-based learning and team learning. Whether the entrepreneurship projects will be presented to real investors for investment depends on the relationship with industries and the support from the universities.

In relation to teaching approach to initiate the entrepreneurship project, EE in business schools is mostly based on the market-pull approach while TEE courses in engineering schools are technology-push approach [24, 25]. The "Turning Technology into Business" approach is a clear example of technology-push [21]. Business schools follows the following path: Market opportunity, customer need, a product idea and business plan while. In contrast, the TEE course follows the path from technology identification, business idea, product concept, and then business plan with a view to transferring the technologies and at the same time solve a problem.

The two different approach was even reported in the same university, for example, MIT [25]. The grand challenge project by the X Prize Lab at MIT takes a very obvious "market-pull" approach. Students identify a market need first via the empathy with customers and then think about how to solve it later. However, the Innovation Teams course at MIT takes a technology-push approach by which students develop commercialization strategies for MIT ready technologies.

2.5 The results (for which)

Talking about the assessment of the results, there are two levels on the reviewed courses and program [16]. One level is the contribution to the community development and economy and the other level is the success of the programs in terms of startup new companies. However, as an education course or program, there is a missing in the assessment of students learning. No references report the detail learning assessment criteria and the methods to assess the learning objectives of the courses or programs, which most teachers will be interested to know.

2.6 The deliver (by who)

Traditional entrepreneurship courses and programs are mostly offered by business schools, the offers are very obvious. However, for those entrepreneurship courses in engineering schools, who offer these courses is a concern and an important issue. Standish-Kuon (2002) reported three models in terms of who is the host schools of engineering entrepreneurship courses, namely, business school (model A), engineering school (model B) and combined (model C). Among the TEE courses/programs reviewed in this paper, two are offered by business schools [9, 20, 21], four are offered by engineering schools [15, 19, 22, 23] and only one is offered jointly by engineering and business school [18].

After reviewing and comparing the above eight TEE models, it can be found that technology-based entrepreneurship (TEE) education programs offered by engineering schools or in collaborations with business schools aim to teach engineering students to identify business opportunities from existing or under developing technologies with a view to transferring and commercializing the technologies

from universities to research laboratories. The teaching approach by TEE is mainly based on technology-push strategy. The audiences are mainly science and engineering students but business and other students are not excluded. Technology-based entrepreneurship education (TEE) incorporates the key elements of conventional entrepreneurship education, but concentrates on the creation of economic value from technology and innovation [20]. The direction and objectives of TEE are very obvious and unique. However, a major problem with the programs and courses reviewed is that they miss a clear and simple model on the operational level. The model and details are still general (maybe due to space limitation in the papers) and the assessment of student learning is mostly missing.

It is necessary to distinguish the EE by business schools from the TEE in engineering schools since the audience and teaching approaches are different [18]. Back to the 1990s, there has been EE courses offered to science and engineering students. However, these courses are not necessarily technology-based entrepreneurship but similar to traditional EE. The only difference is the audiences (target students). Authors suggested that TEE programs should be designed differently especially when it is taught to engineering students [18, 20]. In the next section, a model for TEE at a university in Hong Kong will be introduced.

3. The TIPE model for teaching technology entrepreneurship

The TIPE is an acronym stands for Technology, Idea, Product and Enterprise. The TIPE model is a step-by-step concise and effective teaching tool that aims to help students to identify technologies, generate new business ideas, design a new product and finally develop a simple business plan. The PIPE model was implemented in a course titled Technological Innovation and Entrepreneurship for a master program and doctor students since 2001. The TIPE model will be introduced following the 5W1H model [16] as highlighted in **Table 2** and elaborated below.

3.1 The audience (for whom)

A course based on the TIPE model was first offered in 2001 for a master program in manufacturing engineering and engineering management. The students are both part-time and full-time. The class sizes range from 50 to 80. So as to the background, most students have a bachelor degree in engineering or science subjects while a few from management schools majoring in information systems or technology management. For the moment, about 60% are from mainland China, 15% from Europe (mostly from France) and 25% from local.

Now it is planned to be expanded to 5 master programs in its college of engineering including system engineering and engineering management (core), bio-engineering (core), mechanical engineering (elective), e-commerce and computer science (elective), and electrical and electronical engineering (elective). For this expansion, two or more classes will be offered due to the number of students increase.

3.2 The deliverer (by who)

The course was developed and offered by the Department of Advanced Design and Systems Engineering, College of Engineering. The course was run by one lecturer plus one tutor plus one or two guest speakers with entrepreneurial experiences. Students can also join entrepreneurship competitions run by Technology Transfer Office (TTO) and the other external organizations.

TIPE Details:	Technology	Idea	Product	Enterprise
Content (What)	Exploration and discovery	Creativity and creative thinking	Innovation and new product development	Entrepreneurship and business plan
Learning objectives (Why)	To identify technologies from patents or their own research	To generate new business ideas based on the technology	To propose and design a product under the business idea	To incorporate all the above factors into a business plan
Teaching and learning activity(How)	Eye (Explore & search)	Brain (think creatively)	Hand (Design and make)	Feet (Go to market)
Assessment criteria of the learning outcome (For which)	• The source of technologies • Technology readiness level (TRL) • Relevant to team background	• Originality and attractiveness • Number of ideas generated • Impact of the ideas	• Technology support, • Technical feasibility, • Product uniqueness and IP protection	• Market feasibility • Financial feasibility • Team spirit and collaboration
Milestone assessment (How assess)	Technology search report	Business idea report	Product design report	Business plan report

Table 2.
The PIPE model for teaching technology-based entrepreneurship.

3.3 The objectives (why)

The course based on the TIPE model aims to train students to identify business ideas from new technologies of their interest with a view to commercializing the technologies via new startups. The objective is shortened as turning engineers into technology entrepreneurs or technology transfer service and consultation in the future. One uniqueness of this TIPE model is the step by step process along which the learning objectives of students can be elaborated and implemented. Along the 4 steps of the PIPE model, the student learning objectives under the outcome-based education theory are:

1. To identify technologies from patents database or their own research,

2. To generate new business ideas based on the technology,

3. To propose and design a product under the business idea and finally

4. To incorporate all the above factors into a simple business plan.

3.4 The content (what)

The content of this course is highlighted by the TIPE model, including abilities to identify technologies, generate new business ideas, design a new product and finally develop a simple business plan, which are corresponding to discovery, creativity, innovation and entrepreneurship. The course was designed to be a 39-hours course bearing 3 credits according to the credit calculation formula by the university. The course was run in one semester. So far there is no concern about the credit in terms of time and space for this technology entrepreneurship course since it is either a core or elective designed into the master and doctor programs.

The content of this course is at the stage of preparing technology-based entrepreneurship. Implementation is not a compulsory due to time limitation. In the future, the implementation or execution should be considered. That means more hours or courses will be needed. One course is not sufficient to deal with both preparation and the implementation.

3.5 The method (how)

The TIPE model was designed to guide student-centered learning from multidisciplinary perspectives. The course is based on a team project. The team contains of 5–8 students. The final outcome is a business plan to pitch to an industrial panel. The project is also the learning vehicle, by which students work together and learn collaboratively. The course is process-oriented. It goes step by step along the TIPE model. Students know where they are at any time. However, process orientation does not mean the learning is a linear process instead, there are a lot of back and forth along the process, which students have to get familiar with. The course following the philosophy of learning by doing or experiential learning. It is student centered: i.e., the course is for the students, the project is run by the students, and ideas come from the students. At each step, students know what to do and how to do. Teachers are more or less a facilitator and helper. Case studies are used to the minimum level while mini-cases are presented as examples to stimulate students. The technology-push action case is encouraged for engineering students. For example, we normally started with previous student examples of our university. The following is a recent one:

An engineer developed a tiny equipment that can generate various types of smell and registered in the US and China Patent Offices. That research project finished! A group of students who were involved in an entrepreneurship competition try to use this patent technology to develop new products. The end of the day, the proposal is a new VR with smells of flowers! They joined the local competition and earned the ticket to join the poster competition in the US Grand Challenge Scholar Program.

Then two assignments will follow the mini-cases for students to practice the concept "from technology to product ideas":

a. A scientist develop an instrument that can understand the singing of a bird. He registered a patent of the technology, can you think of any business ideas based on this technology?

b. Nano-materials can be so clean that they do not need to be washed. Can you think of any product ideas that are based on this feature of the Nano-materials?

To initiate the team projects, the students will be encouraged to search patents database of the university as well as any other public patents sources that the students may get access to with a view to looking for technologies that they are familiar with and interested in. They can also talk to their technical professors that they are familiar with during previous bachelor studies about this possibility to commercialize the professors' technologies. In the past years, roughly 40% technologies are from university patent data base, 30% from public patent websites, 10% from students' previous studies and 10% from others sources such as their own research, companies and parents.

Although technology-push approach is strongly recommended in this course, it does not mean the market-pull approach is excluded. A few students who do not have technological backgrounds may come out of business ideas based on a market need. But they are encouraged to look for technologies to solve the problem so that their projects are still regarded as technology-based. If they still cannot make a technology-based project, they are advised to join other teams based on technologies.

3.6 The assessment (for which result)

There are two levels of assessment criteria and assessment scheme, one is about the assessment of student learning while the other is about the effectiveness of the course in terms of startup or contribution to the community. As a credit bearing formal course, the top important one is the assessment of student learning since the all students joining the course has to be graded.

The student outcomes assessment under the TIPE model cover two aspects, namely, the accomplishment in terms of the learning objectives and the preparation of a simple business plan. The assessment scheme is based on continuous assessment philosophy at 4 major milestones by presentation or discussion with the lecturer/tutor, as shown in **Table 2**. The assessment reports include: the technology search report, the business idea report, the product design report and finally the Business plan report for pitching to industry panel.

The whole assessment scheme includes class activities and assignment (30%), group project (30%), final test (30%) and within team peer assessment (10%). The within team peer assessment was introduced recent years since it was found that some students tended to take a lift during the whole semester. It was also found that the peer assessment can pretty easily identify those who take a free ride.

The course based on the TIPE model can be regarded as successful from education perspective. Students' feedback are very positive and the teacher got teaching excellence award twice for this course. However, there is no data to justify whether

it is a successful course in term of real technology commercialization and startups. There are mainly two reasons to explain this.

First, the master program is a one year program for full-time students and two years for part-time students. For the moment, the course is in the last semester and focuses on the preparation stage and does not require the implementation due to time and resources limitation. The part-time students will be busy with their work and will not have additional time to follow up the startup of a companies, while the full time students will leave the universities for jobs one year after and do not have time to utilize the startup supports from the TTO and the government. Some students are international and will go back to their home countries after the graduation.

Second, although the university encourages technology commercialization and promulgated a very clear policy on technology commercialization, the academic promotion and annual evaluation of the faculties (researchers) are still based on academic performance like publishing academic papers and raising research fund. Academic faculties are happy to support the students who selected their technologies in their project but will not have time and incentives to go further for real commercialization afterwards.

4. Discussions and implications

Technology-based Entrepreneurship is related to discovery, creativity, invention, innovation and technology, which are likely to be confused and are difficult to be taught in one course [26]. It is not useful to discuss which covers which since there are overlapping. The TIPE model distinguishes discovery, creativity, and innovation and entrepreneurship, focuses on the core of these concepts and then integrates them into one model. It is based on the technology-push approach to support technology transfer, although the market-pull approach is not forbidden since a few students do not have strong engineering backgrounds.

The PIPE model is not only for designing and developing a TEE course, but most importantly also for the students to learn the course by doing the projects. The model should be simple and clear without too complicated managerial theories and concepts. Engineering students are relatively logical and linear thinkers and are action oriented. They are weak in management theories. So the model has to be simple, concise, visual and easy to remember and understand at the first glance and then can be elaborated step by step. **Figure 1** is the simplified visual version of the TIPE model shown to students in the first introduction class. The diamonds stands for so-called diamond thinking, starting with divergent thinking and ending with convergent thinking.

The TIPE model has been running for many years and will be expanded to more master programs. The preparation of this paper provides an opportunity to study previous TEE models, review the TIPE model and the course, identify limitations and explore implications for future development. The paper and the program trigger the following discussions.

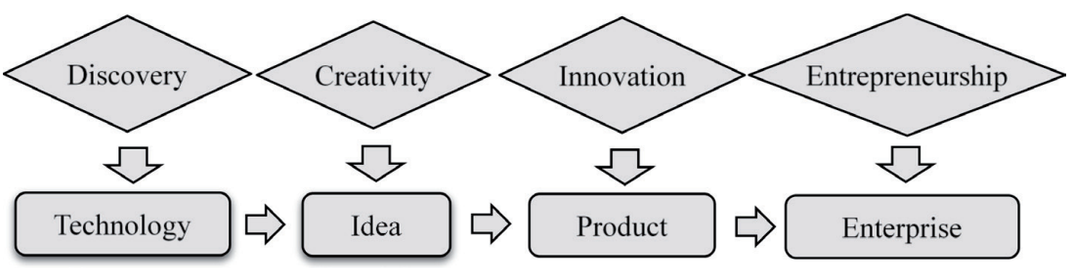

Figure 1.
The TIPE model for teaching and learning technology-based entrepreneurship.

4.1 The collaboration between business schools and engineering schools for an interdisciplinary program

Talking about the content, the course based on the TIPE model covers only the stage of preparing technology-based entrepreneurship. Implementation is not a compulsory. In the future, the implementation or execution should be considered. One course is not sufficient to deal with both preparation and the implementation in one semester. That means more hours or more courses are needed for the implementation in terms of investment, marketing, company management, and company registration etc. For a master program in engineering direction, there will be space and time limitation to include more management courses. So a more entrepreneurship oriented program jointly offered by business and engineering school may solve the problem. This focused program may be run by the college of engineering, instead of individual departments. If students are weak in management, it will be difficult to implement the business plan.

This limitation is not alone with the TIPE model. Audretsch et al. [27] found that technological entrepreneurs out of the university context focus much more on the scientific and technological aspects of their start-up ideas than managerial aspects. When reviewing a TEE self-study manual by Swamidass [28], Hutchinson [29] found out the major weakness is the insufficient coverage of business model and the business plan. This is perhaps a common problem in other TEE courses as well. How to turn engineers into entrepreneurs need not only technology but also managerial contents. With only one course on entrepreneurship is a good beginning to plant the seeds of technology entrepreneurship but may not be sufficient to prepare technological entrepreneurship in terms of business model and business plan, which can be two separate courses in a MBA program by business schools. This problem is related to both the content, the length of the course or program and the deliverers of the course. This implies that the collaboration between business school and engineering school is necessary to develop an interdisciplinary comprehensive program on TEE.

4.2 The balance between technology-push and market-pull to see the two sides of the same coin

As the previous models of TEE, the teaching methods in the TIPE model include team-based project, student centered learning, and pitch to an industry panel etc., which will be maintained in the TIPE model in the future. However, these methods are not really unique with TEE. What is really unique and special with TEE is the way to initiate the entrepreneurial project. As reviewed before, there are two opposite approaches to initiate entrepreneurial projects, namely, market-pull and technology-push [24]. It is very obvious that the TIPE model is based on the technology-push approach. Having said that, it does not mean market is ignored along the TIPE process. Comparing the two different approaches used simultaneously by two programs, respectively, at MIT, Wolfson [25] believes that market-pull and technology-push is the two sides of the same coin of entrepreneurship. A successful startup needs both a well-defined problem to solve and a well-formed technology that solves the problem. However, a project has to start somewhere, either market or technology. Technology-based entrepreneurship from the technology transfer perspective will start with technology normally. But no matter where to start with, the market need or the problem (the pain) and the technology or solution will meet sooner or later. It is only a time issue. In fact, it is better for the technological solution and the market need to meet as early as possible to justify the match or fit. Whenever talking about a match, it involves two sides, like a man and a women in love. Consistent with the discussions on the content, TEE students need to know both technological and managerial

concepts like customer and market need in order to match and integrate both. Munro and Noori [24] has recommended the integration between the market-pull and the technology-push approaches in new product development. The balance mindset between the technology and the market should be introduced into TEE.

While we emphasize the priority of technology-push in this paper, it does not mean all technology-based entrepreneurship course always starts with a technology. Kang and Lee [30] report a capstone course of technology entrepreneurship at a software department, where students identify a social problem first and then try to solve the social problem with technologies like Arduino, Raspberry Pi, and sensors.

4.3 The balance of short term and long terms effectiveness of TEE

In the assessment of the TEE effectiveness at community level, some TEE models report cases of startup after the course running. Number of startups is attractive and impressive and should be encouraged. However, the number of short term startups may not reflect the real future potential of TEE from education point of view [10]. Pretty much research on what factors influence the intention and action of students and finally becoming entrepreneurs in the future has been conducted in the context of EE in business schools. The effectiveness of TEE from a long term perspectives has not been well researched. Such research on TEE seems to be at the preliminary stage without solid theoretical basis (i.e., Militaru et al. [31, 32]). The theory of planned behavior (TPB) [33] and empirical research methods (i.e., [7, 34]) can be applied in the TEE context as well.

4.4 Downstream entrepreneurship policy

As discussed before, there are two levels of outcome of entrepreneurship courses. One is student learning in terms of achieving learning objectives while the other is the effectiveness of the course in terms of startup or contribution to real technology transfer and commercialization. Since a course normally lasts just one semester, it normally ends with preparation of a business plan and there is not enough time and resources to implement what students have proposed in the course. Therefore, there should be relevant downstream policies for going further.

Nelson and Monsen [35] reviewed several references on technology commercialization and concluded that technology commercialization coves a broad range of activities, including startups, spinouts, licensing, collaboration, contract research, consulting and open innovation [36–39]. Therefore, it is necessary to explore relevant policies in the following areas:

How to encourage students to go further to implementation?
Where students can find investment?
Where students can find managerial training and supports?
Where students can find support to explore potential clients and market?
Where students can find suppliers and materials?
Are there sufficient incubation capacity in the community?
Are there relevant tax polices for new technology start-up?

5. Conclusions

This paper reviewed previous models on TEE and reveals that entrepreneurship education (EE) and engineering entrepreneurship education (EEE) are not very different except audiences and delivering departments. However, TEE and EE are quite different in terms of the objectives, the contents and especially the teaching

approaches. What makes TEE special is the technology-push approach and the possibility to be linked with another stream of research and education, namely, technology transfer (TT).

The TIPE model introduced in this paper distinguishes technology, creativity, and innovation and entrepreneurship and then integrates them into one process-oriented model. It helps to remove the confusion among creativity, innovation and entrepreneurship. The TIPE model belongs to the category of TEE in term of the audience, objectives and teaching approach. The TIPE model is implemented in a one-semester course for master programs in an engineering school. The step by step continuous assessment of student learning was reported. However, the effectiveness in terms of students' startups cannot be justified yet since it focuses on the preparation stage due to time limitation.

There are a few limitations of the paper which can lead to future research. First, compared with entrepreneurship education at business schools, there are not many examples of technology-based entrepreneurship models to review. This can be enhanced in the future if more cases emerge. Second, although the TIPE model have been implemented for some times, we did not conduct assessment yet. The assessment models by Kazakeviciute et al. [9] and Purzer et al. [40] can be adopted for this purpose. Finally, this paper reviews the TEE at a course level, future research can also review TEE at program level. There was report of technology entrepreneurship course for PhD student [41], which was not included in this paper since this paper covers only undergraduate level. Of course, the policy issues for downstream technology entrepreneurship action will be a new area of future research. Whatever, the review and the model in this paper can be a reference for any teacher to develop technology-based entrepreneurship education courses.

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