Kruachottikul *et al.*
Journal of Innovation and Entrepreneurship (2023) 12:48
https://doi.org/10.1186/s13731-023-00311-1

Journal of Innovation and Entrepreneurship

RESEARCH Open Access

New product development process and case studies for deep-tech academic research to commercialization

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Abstract

This research proposes a new product development (NPD) framework for innovation-driven deep-tech research to commercialization and tested it with three case studies of different exploitation methods. The proposed framework, called Augmented Stage-Gate, integrates the next-generation Agile Stage-Gate development process with lean startup and design thinking approaches. The framework consists of six stages and five gates and focuses on critical thinking to help entrepreneurs avoid psychological traps and make the right decisions. Early activities focus on scouting for potential socioeconomically impactful deep-tech research, developing a business case, market analysis, and strategy for problem–solution fit, and then, moving to a build–measure–learn activity with a validated learning feedback loop. Next, suitable exploitation methods are decided using weight factor analysis, developing intellectual property (IP) strategy, completing the university technology transfer process, and participating in fundraising. To pass each gate, the committee board members, consisting of tech, business, IP and regulatory, and domain experts, will evaluate the passing criteria to decide Go/No-Go. Applying the framework to the case studies results in successful university research commercialization. The model, case study, and lessons learned in this paper can be useful for other deep-tech incubator programs to successfully launch deep-tech research for commercialization. The case studies' positive outcomes validate the Augmented Stage-Gate framework, yet their success is not entirely guaranteed due to external factors like regulatory constraints, entrepreneur characteristics, timing, and the necessary ecosystem or infrastructure, particularly in emerging markets. These factors should be taken into account for future research purposes.

Keywords: Entrepreneurship, Technopreneurship, New product development, Innovation, Deep-tech, Research to commercialization, Technology transfer, Intellectual property

Introduction

Deep-tech innovation is a new wave of impactful innovation that drives the economy and society. Unlike digital innovations such as mobile apps and digital platforms that disrupted many old-fashioned businesses in past decades, deep-tech is unique, high-value, hard-to-reproduce technological or scientific advances that will improve the technological frontier or disrupt existing solutions and result in socio-economic impacts (De la Tour et al., 2017). Deep-tech innovation is usually led by megatrends and unmet needs (Linden & Fenn, 2003).

Thailand, a developing country, relies heavily on traditional businesses such as sales, marketing, and services. Thailand's gross expenditure on R&D (GERD) is lower than that of other middle-to-high income countries. In 2018, Thailand spent 1.11% of gross domestic product (GDP) (182 billion baht) compared with an average of 1.41% for the upper-middle-income group and 2.43% for high income countries. GERD was expected to reach 2% of GPD in 2027 but this was revised to 1.46% due to the COVID-19 pandemic, assuming no new measures to boost R&D investment. Nevertheless, various government policies require stimulus to R&D spending, especially for SMEs and innovation-driven enterprises through the Thai Bay-Dole Act (Office of National Higher Education Science Research and Innovation Policy Council, 2021). Therefore, deep-tech innovation applied to Thai businesses could be a potent new driver for its economy. Since most deep-tech originates from academia, researchers, patents, or publications, it is unlikely to be successful and sustainable without real demand from users or direction from the business side. This is because traditional academia focuses heavily on research, publication, and prototype development (Fellnhofer, 2016), rather than building a product that is ready for commercial use (Hicks et al., 2009). Promoting entrepreneurship, which is a combination of art and process to pursue opportunities and turn into a business regardless of resources, among academia can be helpful to create environments that support innovation development (Barringer & Ireland, 2012).

Moreover, many deep-tech innovations require a large amount of funding at the initial stage to build a prototype, perform user validation, and develop a business strategy. Additionally, deep-tech innovation is new, and the industry may not be clear about market needs or potential buyers. Therefore, the technology acceptance model (TAM) is used to understand predictors of human behavior toward potential acceptance or rejection of the technology, particularly technologies related to information and communication technology (ICT) (Lee et al., 2003). It can also provide a useful tool to assess the success of new technology introductions and help understand the drivers of acceptance to proactively design interventions targeted at users that may be less inclined to adopt new systems (Venkatesh et al., 2003). After validating the market and technology, it is time to decide on commercialization options (Yaldiz & Bailey, 2019).

For deep-tech innovation to become successful exploitation from the research ideation stage until commercialization, it requires a product development model suitable for university research initiation and developing market environment. Meanwhile, many pieces of prior research on the NPD model and case studies were primarily conducted based on developed countries where the product development was done within the established company ecosystem (Cocchi et al., 2021; Cooper, 2016; Cooper & Sommer, 2016, 2018; Salvato & Laplume, 2020; Walrave et al., 2022; Wuest et al., 2014). However, this study highlighted the importance of a specific NPD model in the academic initiative context with low resources and a lack of infrastructure setting, which generally happens within developing countries (Ravi & Janodia, 2022a). This study is essential to promote deep-tech in Thailand and to help other developing countries that require a new growth potential to drive the economy. Consequently, to accelerate deep-tech innovation in Thailand, the Chulalongkorn University Technology Center (UTC) was established in 2019 as a platform to spring-board academic research to commercialization and facilitate among stakeholders within the ecosystem based on triple helix model, which promotes the way of working that the government, private sector, and academia must collaborate to form a solid, deep-tech innovation ecosystem (Leydesdorff & Etzkowitz, 1998) to support manpower, finance, know-how, production facilities, regulation, and sandbox testing in order to expedite the speed of innovation development.

This study uses qualitative research and observation based on the actual case studies of the UTC portfolio research teams. The goal is to understand the pain points, needs, obstacles, and processes required for the successful exploitation of their project and then extract the vital insightful factors for applying to the NPD model, which will be later discussed in the Methods section.

To develop the proposed NPD model, several related NPD studies have been reviewed. Then the next-generation stage-gate development system integrated with agile development, lean startup, and design thinking methods is selected and then applied together with the insights obtained from qualitative research as the NPD model to develop successful business-driven deep-tech innovation. The effectiveness of the model is later tested and confirmed using both experts and observation, which will be later described further in the Results section. This framework, which we call the Augmented Stage-Gate framework, is important for successful innovation and is based on critical thinking. Because human decisions are influenced by the subconscious, it is essential to make decisions based on the results of logical reasoning and avoid psychological traps (Linden & Fenn, 2003).

In addition, three case studies are explained and discussed. Applying the Augmented Stage-Gate framework results in successful commercialization process in all three cases where the teams transferred the technology via a spin-off startup with a patent, non-profit use with trade secret, and licensing. The benefits of this study can be used as a framework and case study for successful deep-tech innovation development and commercialization, especially in the context of developing markets and academic research initiation. Several options are proposed and discussed. Finally, the study makes several recommendations for future research, including its application to other vertical deep-tech innovation areas.

Literature review

In this section, the literature on the NPD model, TAM model, and product readiness assessment is discussed. Generally, the NPD model, is a nonlinear and iterative process based on a problem-solving approach that is used for the conception, development, and launch of new products or services. It can help management understand user insights, challenge assumptions, redefine problems, and create innovative solutions to prototype and test with target users to successfully launch in the market. In addition, the NPD process is based on critical thinking, which is the ability to look at events, conditions, or thoughts with a careful eye and make decisions about the reliability and validity of the knowledge according to standards of logic (Seferoglu & Akbiyik, 2006). It involves identifying and analyzing informational sources for credibility, indicating previous knowledge, making connections, and deducing conclusions (Thurman, 2009). Higher-order thinking ability provides the opportunity to analyze the existing knowledge or situation to correct mistakes and complete deficits to reach correct conclusions (Howard et al., 2015). In this study, the authors select Stage-Gate, which is a macro idea-to-launch product development planning process that involves the Go/No-Go decision-making (Cooper & Kleinschmidt, 2001), as the baseline NPD framework because the model is easy to understand among stakeholders in a simple linear system format that consists of detailed guidelines for every stage and explains the criteria for management to make a decision whether to allow the development to pass each gate. These unique characteristics of Stage-Gate model strongly fit within the context of our study. While its principles can be applied, the Stage-Gate model, including the number of stages, activities, and gate criteria, has to be adjusted according to our objectives using the insights obtained from this study.

After the core concept of Stage-Gate model was chosen, several modern State-Gate models were reviewed. The next-generation Stage-Gate process that comes with the Triple A system and spiral concept that promotes the development process to be adaptive, flexible, iterative, and accelerated using a feedback loop from user validation (Cooper, 2016) can be applied to the model. Furthermore, there was a study of applying Agile project management methods, which highlights a process that is a dynamic planning process that is adaptive and flexible to changes in product development, into a traditional Stage-Gate system, called Agile-Stage-Gate Hybrids. The results looked promising for faster product releases, quicker and better responses to changing customer requirements, and improved team communication and morale (Cooper, 2016). Moreover, case studies in manufacturers conducted by R. Cooper in 2018 also supported the earlier finding; yet it also added some challenges in terms of management buy-in, resources needed and allocation, and fluid product definitions and development plans (Cooper & Sommer, 2018). These insights are also similar to the study by Zasa et al. (2020) who highlighted that agile project management will increase interaction among project stakeholders and help break big tasks into small and achievable action items (called *sprints*) within a short period of time. They also suggested that successful implementation required the integration between traditional project planning modes and the agile method, cultural change, and perceptions of all stakeholders in the organization (Zasa et al., 2020).

Therefore, by applying modern concepts of Stage-Gate like triple A system with spiral concept and agile development, the earlier Stage-Gate baseline model can be improved in many ways. That is, the model becomes more adaptive and flexible to changing customer requirements and situations, increasingly improved team communication and morale, and further highlights on an iterative process to promote interfacing between the development team and the target user. Moreover, the importance of interfacing with users iteratively for business assumption validation is also similar to the principle of lean startup and design thinking. The lean startup encourages startups to challenge business growth hypotheses and use them to build the minimal viable product (MVP), then test and validate with the real user to learn whether it is required to pivot or preserve. This can be repeated many times during the NPD process; an approach called build–measure–learn (Ries, 2011). On the other hand, design thinking uses a designer's sensibility and methods to match people's needs to what is technologically feasible and a viable business strategy that can be converted into customer value and market opportunity (Brown, 2008).

In addition, the TAM can be useful to consider during the NPD process, in particular with ICT-related technologies. It can provide information regarding the probability of success during the introduction of a new technology and the key drivers of user acceptance to enable proactively designed interventions and strategies targeted at populations of users who may not be inclined to adopt new systems (Venkatesh et al., 2003).

Lastly, the authors review the study of product readiness assessment. This is important for our context because there is a misalignment issue from different stakeholders when evaluating the readiness of the new product development. This is a typical problem found when the product is not ready for commercial. Yet the team has to communicate readiness level with stakeholders for different purposes such as fundraising, selling, field testing, etc. The first assessment is the technology readiness level (TRL) which was introduced by the National Aeronautics and Space Administration (NASA) in the 1970s. It is a well-recognized and useful tool to determine the maturity of new technologies. It is also a discipline-independent program that enables more effective assessment and communication. Its nine assessment levels are beneficial to determine the readiness of new technology and/or capability during the technology life cycle, which includes the completion of systems analysis and conceptual design studies, determination from several design options, and decision to start full-scale development (Mankins, 2009). Another assessment is the investment readiness level (IRL) proposed by Steve Blank in 2013, which is also divided into nine levels. IRL is used to evaluate how investment-ready a technology is by validating its business model to help investors assess the risk of investment (Blank, 2014). Investment readiness can be defined as a set of business development processes that increase business venture readiness as candidates for equity investors (Aernoudt et al., 2007). Alternatively, it is the capacity of the business venture to look for external funding, especially from an equity investor, to understand the specific needs required by an investor and be able to give an investor an attractive business proposal with high confidence (European Commission, 2006). Entrepreneurs need information and advice on the advantages of raising equity financing, what it means, and how to become investment-ready (Mason & Kwok, 2010). In addition, Australia National Investment Council. & Marsden Jacob Associates (1995) proposed that businesses that are not investment-ready are primarily the result of a lack of information. This means that they do not know about the role of equity finance and are unaware of what is involved in raising money, what is required to attract investors, and how to convincingly express their investment proposals (Australia National Investment Council. & Marsden Jacob Associates., 1995).

Methods

In this research, the authors use the next-generation stage-gate process as the baseline for the NPD process and then propose the modified NPD framework for new deep technologies that are more suitable for academic research initiation to commercialization in developing markets, called the Augmented Stage-Gate framework. The framework was designed using the insights obtained from in-depth interviews of 19 research teams who had been working on deep tech research and entered the three-month entrepreneurship development program in 2019. The interview was conducted at the end of the program and focused on understanding the pain points in the research-to-commercialization process in terms of entrepreneurship, business development, networking, financial, technology transfer process, progress assessment, and goal. After careful analysis, several recommendations were proposed and integrated into the Augmented Stage-Gate framework as shown in Table 1.

The Augmented Stage-Gate framework highlights more on the Agile development process, flexible entrepreneurial development program, progress assessment using TRL and IRL, process management specialist to guide along the academic research to commercialization journey and bring in a network of business partners and legal experts to support. Its structure is divided into six stages (innovation ideation, build business case, development, test and validation, launch, and scale-up) with five gates (screening, go to development, go to test, go to commercial, and post-launch review). Here, stage means the process for work to be completed, and gate is for the Go or No-Go decision-making. TRL and IRL assessments, as shown in Table 2, can be used to evaluate progress in terms of technology and business readiness at each stage.

The Augmented Stage-Gate framework applies the principle of the next-generation Stage-Gate's triple A system and spiral development, which aims to overcome the typical

Table 1 Pain points and recommendations that are incorporated to develop the Augmented Stage-Gate framework

Pain points	Recommendations
Uncleared business requirement and do not have yet-to-be-developed commercial applications	Encourage startups to set up the market hypothesis and then test, measure, and learn with the target users with a faster, more iterative, and inexpensive process
Lack of entrepreneurship knowledge and skill, and no time to commit to a new full-time business venture	Provide a flexible and systematic entrepreneurial development program and innovation clinic along the way to help increase skills, confidence, and entrepreneurship mindset to be ready before setting a new venture
Lack of business network	Connect to the network of mentors and alumni who have business backgrounds in the same domain
Require large amount of financing	Encourage the startups to have an awareness, strategy and be active in fundraising activities since the beginning
Research-to-commercialization journey is unclear so sometimes the project team loses confidence and morale	Provide the network of process management specialists and mentors to guide along the whole journey Apply the concept of Agile development process
Need strong help on IP, legal and regulatory related issues as they are important for the business strategy and might be a roadblock	Provide legal experts to assist
The technology and research are complex and hard to be assessed and understood by out-of-domain stakeholders	Encourage the startups to quickly develop and demonstrate the user-facing prototype, which can be non-functional at the beginning, with the goals of measuring customer satisfaction or purchase intent Provide assessment tools for the startups and committees to evaluate and communicate the development progress in terms of technology and business
Require lengthy time-to-market	Encourage the startups to apply the concept of Adaptive and Flexible and Agile development and also find the quick win strategy in order to split tasks and possible to set up the goal for both short term and long term

Table 2 TRL and IRL assessment

	TRL (NASA, 1970)	IRL (Blank, 2013)
Level 9	Actual system "proven" through successful system and/or mission operations	Identify and validate metrics that matter
Level 8	Actual system completed and "qualified" through test and demonstration (in the operational environment)	Validate value delivery
Level 7	System prototype demonstration in the planned operational environment	Prototype high-fidelity MVP
Level 6	System/subsystem model or prototype demonstration in a relevant environment (Group or Space)	Validate revenue model
Level 5	Component and/or breadboard validation in relevant environment	Validate product/market fit
Level 4	Component and/or breadboard validation in laboratory environment	Prototype low-fidelity MVP
Level 3	Analytical and experimental critical function and/or characteristic proof-of-concept	Problem/solution validation
Level 2	Technology concept and/or application formulated	Market size/competitive analysis
Level 1	Basic principles observed and reported	Complete first-pass business model canvas

challenges when handling undefined requirements during initial development, and Agile development, which aims to increase interaction among project stakeholders and help break big tasks into small and achievable action items (Sprints). This is because most customers are uncertain about their needs and so the product definition prior to development is unclear. The triple A model promotes each stage to be adaptive and flexible, agile, and accelerated while the spiral development concept promotes experimentation. This is also similar to what Isaacson (2011) described Steve Jobs' philosophy during his development career at Apple that encouraged project teams to fail often, fail quickly, and fail cheaply. With the benefits obtained from the Augmented Stage-Gate core concept, the product design and definition can adapt to new information, customer feedback, and changing conditions along with multiple iterations of validation activities with users or customers throughout the NPD cycle. In addition, it is important to understand that the details of the process and its functions may differ from project to project, especially with deep tech, academic research initiative, and emerging market environment. Therefore, a flexible gating process must be leaner, faster, adaptive, and risk based. Experienced project teams, mentors, and stage-gate committees are also important to guide startup work throughout the NPD process. Additionally, even though the NPD model is represented in a simple linear format, in reality, it is common that each step can be repeated many times and also go back and forth between stages, depending on the readiness, criteria, and requirement to pass each stage.

Then the effectiveness of the Augmented Stage-Gate framework was tested with three cases, to be discussed in Sect. 4. The cases were research teams that joined UTC in 2019 after the new framework had been designed and completed the final stage of the framework by September 2022. The teams were willing to participate in the study. We gathered the information for the cases via observations and interviews.

The authors directly observed the teams as they moved through each stage of the framework. Tangible results such as actual sales, contract execution, regulatory approval, and certifications, were recorded. The authors also had access to relevant documents related to the development process since the teams were required to submit a progress checklist and presentation slides. Information reported (as appropriate to each stage) includes team, research and development progress, regulatory process, business plan, project planning and concept, product design, milestones, risk assessment, technology verification and validation (MVP), market validation, legal activities, IP status, implementation and operations, sales and marketing, and financial activities. These documents were collected and analyzed for the case studies.

In addition to observation, the authors interviewed the stage-gate committees and two or three people from each team (the principal investigator and 1–2 team members). The interviewees were asked to describe the team's journey, how they applied the Augmented-Stage-Gate framework, and the results they achieved. The interviews also explored any significant challenges encountered during implementation, along with the solutions that the teams developed.

The interviews were recorded and transcribed, with the transcriptions used to create a final summary of the case. The summary was then reviewed and approved by the interviewees. In some cases, we went back to the interviewees multiple times to get additional information or to conduct follow-up interviews when the implementation and results had become clearer.

The Augmented Stage-Gate process of new product development

The proposed Augmented Stage-Gate process, as shown in Fig. 1, is divided into six stages. In addition, the below detail explains the objective, activity, and criteria to pass the gate of each stage (as also summarized in Table 3).

- *Stage 0: innovation ideation stage.* As a technology incubation office, one of the important roles at UTC is to search for impactful deep-tech research in focused areas that potentially impact our way of life and attitudes in all aspects. To achieve this, UTC has been working with various business partners and consultants to gain market insights while studying market research information for mega trends. Using

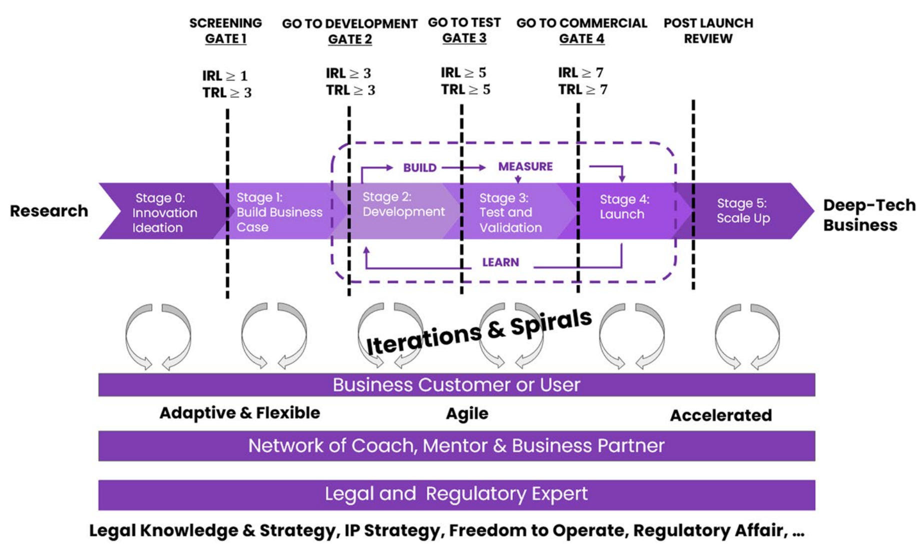

Fig. 1 Augmented Stage-Gate framework

Table 3 Augmented Stage-Gate activities according to each stage

Stage/Gate	Stage 0: Innovation Ideation Decide for the potential deep-tech research for exploitation	Gate 1: SCREENING	Stage 1: Build Business Case Build the potential business case based on core deep-tech research	Gate 2: GO TO DEVELOPMENT
Activities	• Research shows promising opportunities for exploitation • Idea validated by key opinion leaders, domain experts, key stakeholders, target users, etc • Feasibility study on market, technology, and financing • Risk analysis • Obtain entrepreneurship knowledge and skills obtained from various flexible entrepreneurship development programs • Preliminary study of IP assessment, risk analysis, and regulatory plan • Develop early version of value proposition and business model • Develop initial financial management strategy, including financial and fundraising plan • Co-founding team with a mixture of business and technical expertise	Criteria to pass this gate The research project must show the business's potential and financial feasibility and complete the early version of the business model, including target users, value propositions, pain points, and insights. In addition, the team must propose a market assessment and preliminary study of IP, risk analysis, and regulatory plan. In addition, the research team has to show a mixture of co-founding venture teams with both business and technical expertise	Build a real business case and validate earlier business model • Face to face and touching real users • Validate needs, pain points, and requirements • Engaging with coaches, mentors or business partners to validate ideas • Refine business model using the real feedback from users • Stakeholder development Rapid prototype & test & validate problem–solution fit • Test of proposed product early in development • Rapid prototype, crude prototype, or model that is 3-dimensional & physical • Develop simple selling materials • Gauge customer reaction & purchase intent Key human resource development • Secure enough human resources for further development • Entire project team involved Initial IP strategy, including IP identification, IP landscape, and freedom to operate Initial regulatory strategy and risk analysis Financing management strategy • Profit and lost analysis • Cash flow planning • Fundraising planning to secure funding for further development • Typical funding sources include research grants, friends and family, bootstrapping	Criteria to pass this gate The project team has to show the potential of a business case proposal based on core impactful deep-tech research and product prototype that received good preliminary purchase intent or user satisfaction feedback from target users. In addition, the team has to demonstrate an excellent financial and funding plan and initial strategy for IP, regulatory, and risk
Process	Adaptive and flexible	–	Agile	–
TRL	–	≥ 3	–	≥ 3
IRL	–	≥ 2	–	≥ 3
Stage/Gate	Stage 2: Development Develop the workable product prototype with early market validation	Gate 3: GO TO TEST	Stage 3: Test and Validation Final validation of product development. Commercial product is ready and preparation of product introduction	Gate 4: GO TO COMMERCIAL

Table 3 (continued)

Activities	Refine business model closer to final version Develop and refine working model • Similar to Stage 1 • Versions of product much closer to final Customer tests and validated learning • Real prototype tests in actual or nearest in-use conditions • Gauging customer reaction & purchase intent • Continue to refine product and business model using the user feedback Patent review, patent ability analysis, and early patent draft Financial management strategy • Continue to refine financing and funding plan • Participate in fundraising activity • Typical funding sources such as research grants, friends and family, business angels, bootstrapping	Criteria to pass this gate The project team must demonstrate a workable MVP and its validation in the closest real environment or sandbox. A promising result in terms of satisfaction and purchase intent is required to pass the gate. Moreover, the team has to present the initial strategy for IP, regulatory, and risk. Lastly, the team has to have a solid financial strategy and actively participate in funding activities	Develop final version of business model and financial plan • Develop and validate revenue model, business model, and financial model before launching • Always collect feedback from the market and refine business model • Prepare for sales and marketing plan when launching Develop, test, and validate commercial product model • Versions of final product and ready for commercial • Always gauging customer reaction & purchase intent Final patent draft review Financial management strategy • Further participate in fundraising activity if needed • Typical funding sources such as translational research grants, friends and family, business angels, bootstrapping, VCs, loans	Criteria to pass this gate The project team must demonstrate the promising validated near-commercial version of the MVP and revised business model, including sales and marketing plan, according to early market feedback. Additionally, the team must achieve patent ability analysis and participate in funding activity
Process	Agile	–	Agile	–
TRL	–	≥ 5	–	≥ 7
IRL	–	≥ 5	–	≥ 7
Stage/Gate	Stage 4: Launch Market introduction of commercial product. Continue improvement both business and product	Gate 5: POST-LAUNCH REVIEW	Stage 5: Scale up Accelerate target market penetration with full effort	
Activities	• Market introduction using sales and marketing strategy • Collect feedback from early market launch • Newer versions of the product or newer business plans from the market feedback • Decide for commercialization options such as licensing, startup, joint venture, etc Methods used to gather information for post-launch review Lesson learned and recommendations arising from the project Complete IP strategy (protection & management) including university technology transfer process (if have) Financial management strategy • Participate in fundraising activity if needed • Typical funding sources such as Bootstrapping, VCs, loans IP valuation assessment using income, cost-based, or market methods	Criteria to pass this gate The team must launch the commercial version of the product onto the market with positive feedback. Then define the method to collect the market feedback for further refining newer commercial versions of the product and business plan, including the scale-up strategy. In addition, the team must complete the IP strategy, including the university technology transfer process	Collect and analyze the feedback obtained after launch Newer and better versions of commercial products or business plans according to market feedback Accelerate target market penetration with full effort	

Table 3 (continued)

Process	• Accelerated	–	–
TRL	–	–	–
IRL	–	–	–

this information, UTC scouts, classifies, and prioritizes potential research projects. After finding candidates, UTC works closely with them through various programs such as boot camp, workshop, and mentoring to develop the entrepreneurial knowledge and skill in order to help conduct an initial business feasibility study. Another advantage is to give entrepreneurs an understanding of the business journey, challenges, and exit plan so that they can prepare themselves with both skills and morale to be ready before launching. Moreover, the entrepreneurial development program is provided in a flexible format both online and offline to suit with the availability of researchers who might have other full-time jobs at the beginning. Usually, the business model canvas (Osterwalder et al., 2005), with its nine building blocks template, is used to communicate a firm's or product's value proposition, infrastructure, customers, and finances to stakeholders. After completion, the team is ready for the official screening, where the committee board consisting of business, technology, and legal experts will evaluate each research project.

A. The first step is to identify the target customer and study the user journey to understand the pain points and user insights. Additionally, lead users—advanced users who deal with an individual problem very intensively (von Hippel, 1986)—are a subset of target users and can be helpful for the research team to test, validate, and gain valuable feedback on the early development product. Like design thinking, the concept starts with understanding the way customers do things and why, their physical and emotional needs, how they think about the world, and what is meaningful to them. This can be done by carefully observing, engaging, watching, and listening to the users and stakeholders, and then crafting a meaningful and actionable problem statement that focuses on the insights and needs (Brown, 2008).
B. The second step is to analyze internal and external market data. This process aims to understand the business environment and will allow us to better plan so that the threats and opportunities associated with the target area of the business are understood. An internal analysis examines factors within the research project and its co-founding team. The preferred analysis is a SWOT (Strength, Weakness, Opportunity, Threat). Meanwhile, an external analysis examines the wider business environment outside the research project. A popular tool for this is the PESTEL five-force analysis. The key to this process is to ensure that there is market demand to continue the tech-market fit development process.
C. The third step is to complete an initial financial management strategy, including profit and loss analysis, cash flow planning, and fundraising, that can help the entrepreneur understand the business from a financial perspective in different scenarios and help the business thrive. Because deep-tech product development

usually requires a large amount of money and lengthy development time, careful planning in this step is much cheaper regarding business risk. It can avoid cash flow issues that may cause the company to go bankrupt or project delays. Moreover, financial planning can be used to estimate how much investment is needed in each venture development stage so that the entrepreneur can develop a successful fundraising strategy for investors or government grant agencies.

D. The next step is a preliminary study of the IP landscape. This gives the research project a high-level perspective on the constraints and opportunities regarding the potential exploitation and freedom to operate of IP rights. The researchers can conduct this by themselves or consult with the university IP office since normally the university provides IP support through its Technology Transfer Office (TTO) and IP Practicum Clinic, or by outsourcing services to specialized law firms.

E. After that, it is time for regulatory planning to help the research team understand and anticipate what regulations are required for each target market. For instance, Med Tech requires FDA (Food and Drug Administration) for commercialization, IRB (Institutional Review Board) for conducting a clinical trial in humans, and GMP (Good Manufacturing Practice) for manufacturing medical devices. Meanwhile, the PDPA (Personal Data Protection Act) is required to use personal data. Generally, the university technology office can be a helpful resource for regulatory advice.

F. Finally, since deep-tech initiates from academic research by nature, the original research team usually consists mainly of tech-savvy people. Therefore, to become a successful venture, it is crucial to find co-founders with business skills to join the team. Business case competitions or networking events within the university ecosystem can help form an organic partnership.

Criteria to pass this gate	The research project must show the business's potential and financial feasibility and complete the early version of the business model, including target users, value propositions, pain points, and insights. In addition, the team must propose a market assessment and preliminary study of IP, risk analysis, and regulatory plan. In addition, the research team has to show a mixture of co-founding venture teams with both business and technical expertise

- *Stage 1: build business case stage.* The main activity focuses on developing and validating the business model with target users by demonstrating the prototype and then measuring customer satisfaction, interest, or purchase intent. Usually, the prototype in this stage can be nonfunctional and developed based on the concepts of rapid, rough, and right. For example, AI and computer science technology can use UX/UI (user experience and user interface) and wireframe, which is a schematic or blueprint that is useful for thinking and communicating about the software structure among team members, as a prototype to validate the end-to-end solution idea with the user. Moreover, a network of mentors, domain experts, or key opinion leaders, which are mostly university alumni, can be useful resource because they are knowledgeable and experienced, in which they can give truthful advice and validate the solution idea. Another important thing is to interact with real users or customers as early as possible because today users' roles have become more significant as a new source of innovation than in the past, when innovation was created solely from producers and supplied to consumers via goods and services, as described in Schumpeter's theory of innovation in 1934 (Schumpeter, 1934). By working together, the research team can provide product knowledge, engineering, and manufacturing for innovative users to think and be creative (von Hippel, 1976), which means innovators receive an incentive to engage with users to develop innovative designs (Baldwin & von Hippel, 2011).

Criteria to pass this gate	The project team has to show the potential of the business case proposal based on core impactful deep-tech research and product prototype that received good preliminary purchase intent or user satisfaction feedback from target users. In addition, the team has to demonstrate an excellent financial and funding plan and initial strategy for IP, regulatory, and risk

- *Stage 2: development stage.* The main objective in this stage is to develop a workable and functional MVP, validate with the target user, and refine the business model. That is, it aims to improve technology progress and business strategy so that business risk can be reduced. However, it is noted that due to the Agile concept, the startup should target to break the development plan into small and achievable action items so that their hypothesis can be tested and learned often. In addition, validating the MVP in the closest real environment or sandbox, which refers to the environment that allows some players under specific conditions, to enter the market with fewer administrative constraints (e.g., licenses) or legislative requirements (Tsai et al., 2020), is recommended to move the MVP and business closer to the commercial version.

Criteria to pass this gate	The project team must demonstrate a workable MVP and its validation in the closest real environment or sandbox. A promising result in terms of satisfaction and purchase intent is required to pass the gate. Moreover, the team has to present the initial strategy for IP, regulatory, and risk. Lastly, the team has to have a solid financial strategy and actively participate in funding activities

- *Stage 3: test and validation stage.* The goal in this stage is to obtain a commercial version of the MVP and business model. To do that, the lean startup's validated learning concept is applied to this stage because it can show whether the innovation development and business are moving in the correct direction according to the business model. If not, the innovation can be pivoted; a structural course correction to test a new fundamental hypothesis about the product, strategy, and engine of growth. To make the validated learning successful, cause-and-effect questions with actionable and quantitative metrics are essential. After the new features of the MVP are developed, it will be measured with the user to determine if it demonstrates business growth according to the underlying hypothesis, a process can be repeated many times. The benefit of embracing validated learning is to substantially shorten the developmental cycle.

Criteria to pass this gate	The project team must demonstrate the promising validated near-commercial version of the MVP and revised business model, including sales and marketing plan, according to early market feedback. Additionally, the team must achieve patent ability analysis and participate in funding activity

- *Stage 4: launch stage.* The main goal for this stage is to introduce the market of commercial products. The technology development team participates in a build–measure–learn activity to reach the closest version of a commercial product, while the business development team focuses on delivering a commercial final version of the business plan, sales and marketing strategy, IP strategy, regulatory planning, team formation and financial strategy to select the best commercial option with the highest probability of success and return on investment. In addition, if the university IP is used, the team must complete the technology transfer process. Moreover, according to the business model canvas template, this step must ensure that all nine blocks are validated with stakeholders in a way that leads to business growth and the commercial version of the MVP is refined accordingly. The next step is to finalize the IP submission and strategy, consisting of the final IP draft, valuation, and portfolio management, to obtain optimal legal protection and manage the IP effectively. IP valuation, calculated using either cost-based, income-based, or market-based methods, is useful for the entrepreneur to decide on a proper commercialization option and IP valuation for fundraising. Thus, it should be finalized before going to market. Even though IP services can be particularly expensive and time consuming for such early-stage endeavors, the benefit obtained from IP valuation and protection with a well-managed IP strategy generally increases company competitive advantages tremendously after successful exploitation.

The university technology transfer process is an intrinsic part of the technological innovation process. It is the process of conveying results stemming from scientific and technological research to the marketplace and to the wider society along with associated skills and procedures. To achieve a successful technological transfer, many factors must be considered. Souder et al. (1990) described seven best practices as analytical, facilities, pro-actions, people roles, conditions, technology quality, and organization. Meanwhile, Gorschek et al., (2006) recommended close cooperation and collaboration between researchers and practitioners. However, both entrepreneurs and tech transfer officers must discuss and plan each option carefully for the benefit of all stakeholders.

After completing the previous steps, it is time to decide on commercialization. Exploiting an innovation is not only about starting a new company, but there are also many other pathways to bring ideas to markets, such as licensing, joint ventures, and M&A (Schaufeld, 2015). Thus, to choose which option is suitable, the entrepreneur needs to consider factors such as market opportunity, IP protection, operation risk, time commitment, return on investment, and investment amount. A complete business plan should be developed and carefully verified, so that entrepreneurs can understand the business opportunities and risks in advance. Table 4 shows an example of an option comparison

Table 4 Option comparison with a weight matrix; score 1 means low and 5 means high

	Weight (1.0)	Option A Spin-off (Score 1–5)	Option B License (Score 1–5)
Market opportunity	0.2	4 (0.8)	3 (0.6)
IP protection	0.2	5 (1.0)	3 (0.6)
Operation risk	0.2	3 (0.6)	5 (1.0)
Time commitment	0.1	2 (0.2)	4 (0.4)
Return on investment	0.2	5 (1.0)	2 (0.4)
Investment amount	0.1	2 (0.2)	5 (0.5)
Total score (5.0)		3.8	3.5

with a weight matrix between spin-offs and licenses. Briefly, the Option A spin-off scores higher than the Option B license, which means it is the more desirable commercial option to an entrepreneur.

Criteria to pass this gate	The team must launch the commercial version of the product onto the market with positive feedback. Then define the method to collect the market feedback for further refining newer commercial versions of the product and business plan, including the scale-up strategy. In addition, the team must complete the IP strategy, including the university technology transfer process

- *Stage 5: scale-up*. This activity focuses on collecting and analyzing the feedback obtained after launch, providing newer and better versions of commercial products or business plans using market feedback, and fully penetrating the target market. Several considerations can be analyzed. The first is to assess whether the product is performing according to pre-defined expectations in terms of technical and business aspects such as functionality, revenues, costs, profits, and so on. The second is to check customer satisfaction or anything that affects the company's value chain, including purchasing raw material, selling the product, and delivering the goods to the customer. Finally, we examine the strengths and weaknesses of the entire NPD process to learn and improve.

Results and discussion

Case studies

The case studies below highlight the importance of having an NPD framework that is adaptable to deep-tech within university research and emerging market contexts, yet extensive enough to cover all the essential components to transform deep-tech research into an innovation that has a high-fidelity MVP, an accomplished business and market strategy, a clear pathway towards implementation in the real world, and a complete IP strategy and technology transfer process from academia IP.

ReadMe

ReadMe is an artificial intelligence (AI) research project application that began in 2013 to perform Thai object character recognition (OCR) in any scene image, which often has high perspective and distortion error, uneven illumination, and different image resolutions. Additionally, the Thai character structure itself is very difficult to read automatically, particularly using software algorithms, because it consists of a syntactic structure of up to four layers and a strict relationship between words. The research team was conducting research and development internally and working with various industry partners. An e-commerce platform and a railway engineering company were contracted to help understand business demand as well as to improve and optimize the AI model for real-world applications. Nevertheless, after many years the technology remained a research project; early customers did not have purchase intent with a long-term commitment although the Thai OCR reading accuracy was high. Upon applying our Augmented Stage-Gate Framework to ReadMe in 2019, we successfully transformed the deep-tech research into a tech startup named Eikonnex AI (https://www.eikonnex.ai/) that has now secured business deals for commercial use in private companies.

At the screening stage, the project's potential for exploitation, validity, market feasibility, and technological feasibility was assessed and found to fulfill all the framework's criteria. ReadMe, a national award-winning research project, was a deep-tech text reader that was in development for six years, had a research prototype proven well in the lab with a TRL of 4 and an IRL of 1, was the state-of-the-art Thai text reader that was more accurate than other better-known OCR technologies, and is a high-potential technology that could impact the business, medical, and transport industries.

Following their selection, the research team carried out innovation framework activities starting with continuous customer validation, that later helped them develop their market research and business plans. A large majority of their customers were banks, driven by the digital transformation trend and strong competition in the financial industry. One of the most challenging and high-volume applications is the personal loan approval credit scoring. Most were unable to automatically read Thai bank statements correctly due to statement template differences from different banks and Thai character challenges, increasing the time required for loan approval. The team saw this opportunity and pivoted their target customer and core technology to become an OCR with automatic template detection to read bank statements instead. After this decision, the team quickly redeveloped their MVP and carried out multiple user validations using the build–measure–learn process. In the meantime, the team worked closely with a network of mentors to adjust and validate the product idea and business plan.

After rigorously applying the framework's validation activities, the technology underwent a complete transformation and reached commercial readiness. The technology now had a TRL of 7 and an IRL of 7, completed the IP strategy by obtaining a patent for their technique, concluded the technology transfer process, and set up a spin-off tech startup. Moreover, in early 2021 a few months after their establishment as a startup, the company received its first business deal from one of the biggest banks and completed the technology transfer process. Currently, the company is making its first sales by providing Thai document reader solution services either as an API or as a customized technology. They will continue to move towards digital transformation and expand into a coherent document digitization platform.

It is clear that with the support, guidance, and structure provided by the Augmented Stage-Gate Framework as explained in Table 5, deep-tech research can be transformed into an innovative, high-impact, commercializable product and company in one to two years.

Table 5 Augmented Stage-Gate activities for ReadMe

Stage 0: innovation ideation	Stage 1: build business case	Stage 2: development	Stage 3: test and validation	Stage 4: launch	Stage 5: scale-up
• ReadMe was deep-tech research in vision AI and the state-of-the-art Thai text reader • ReadMe had a research prototype proven well in the lab with a TRL of 4; yet IRL of 1 due to an early business model and not fit to market needs yet • It was a high-potential technology, and the idea was validated by key opinion leaders in the business domain, especially the digital transformation trend	• Build business case based on the ReadMe text reader • Interview with more than 20 corporates that are interested in digital transformation strategy including banking • One of the prospect applications was a personal loan approval's credit scoring • Rapid prototype development for potential application to solve customer pain points were proposed and validated • Study the IP landscape to find freedom to operate • First draft of business model	• Rapid prototype development for working prototype based on AI algorithm used for statement reader based on customer sample and then validate the result with the prospect customer to see the problem–solution fit • Tests and validated learning using customer data and compare the result with the existing solution • Gauging customer reaction and purchase intent • Team recruitment • Refine business model • Apply for grants • IP draft	• Final version of the business model was developed and validated with early customers • Secure order from early customers in particular banks • UX/UI design and validated with early customers • Continue software development, including UX/UI and software application, to complete the first commercial version and ready to sell • Apply for translational research grants • Prepare for spin-off • Fund raising from friends and family • Study tech transfer process • File an IP	• Complete university tech transfer process and became a spin-off company • ReadMe product is targeted for document reader solutions especially related to digital transformation and then collect feedback in order to improve products • Lessons learned and recommendations used to adjust business models	• Always collecting and analyzing the feedback • Continue development for better versions of commercial products • Expand business into other fields especially accounting related documents • Accelerate target market penetration with full effort
TRL = 4	TRL = 4	TRL = 5	TRL = 7	TRL = 9	–
IRL = 1	IRL = 3	IRL = 5	IRL = 6	IRL = 8	–

Chest X-ray AI reporter for COVID-19

Following the trend in the use of AI for healthcare, the chest X-ray reporter was an R&D project by physicians and computational researchers that aimed to create AI software that could classify and report abnormalities for physicians to consider as part of their diagnosis. Nonetheless, the technology remained a research project as it lacked a workforce to develop the complete application software and system integration and had no exit strategy.

With the application of our framework and the outbreak of the coronavirus (COVID-19) pandemic, the technology met the immediate needs of society by being able to detect COVID-19 and numerous other conditions from chest X-rays. As of the end of 2021, this innovation was used as a not-for-profit technology in the King Chulalongkorn Memorial Hospital, helping many patients in need.

The technology had a TRL of three and an IRL of one at the time of screening with an alpha version of the AI algorithm. As this project is led by physicians and computational researchers who are experts in the field, it is considered a deep technology with high potential for use in hospitals, especially rural government hospitals that sometimes lack healthcare personnel or technology to analyze chest X-rays efficiently. This innovation may also be adapted for use in other types of X-rays for other diseases and undoubtedly has large potential to improve the accuracy of medical diagnosis. Thus, this research is a good candidate for our Augmented Stage-Gate framework as explained in Table 6.

Table 6 Augmented Stage-Gate activities for chest X-rays

Stage 0: innovation ideation	Stage 1: build business case	Stage 2: development	Stage 3: test and validation	Stage 4: launch
• The technology had a TRL of 3 and IRL of 1 at the time of screening with an alpha version of the AI algorithm • The technology prototype shows a promising result as a tool to support physicians to classify and report abnormalities by using chest X-rays	• Due to COVID-19 pandemic, it showed a high-impact use case to apply this research to help physicians to diagnose a COVID-19 patient using chest X-rays • Interview and engage with key opinion leaders • Rapid prototype development for potential application to solve customer pain points were proposed and validated • Study the IP landscape to find freedom to operate • First draft of business model	• Develop end-to-end software application and system integration with the hospital information system and then validate the result with the prospect user to see the problem–solution fit • Gauge customer reaction and purchase intent • Team recruitment • Refine business model • Apply for grants	• Final version of the business model was developed and validated with hospital management • Continue software development to complete the first commercial version and ready to launch on the field • Study tech transfer process • File an IP	• Install the system on the field • Lessons learned and Recommendations used to adjust business models • Work on university tech transfer process on the spin-off model
IRL = 1	IRL = 3	IRL = 5	IRL = 6	IRL = 7
TRL = 4	TRL = 4	TRL = 5	TRL = 7	TRL = 9

Following the development and validation activities of our framework, the research team recruited more AI engineers to develop their algorithms and UX/UI to enable intuitive use of the technology. Here, the code and interface were continuously revised with frequent customer and domain expert validations to select the most relevant features and data for physicians. To protect intellectual property, the technique was kept a trade secret. After using the framework for only one year, the work reached a TRL level of 7 and an IRL level of 7 and gained acceptance for not-for-profit use in the hospital for preliminary screening of COVID-19 and other chest X-ray abnormalities. At present, the innovation is used at Chulalongkorn Hospital. We believe that, with its initial success, the technology can be implemented in other hospitals to help improve patients' quality of life. The project team is now involved in the process of technology transfer and spin-off.

Progesterone test kit

The progesterone test kit for swine is a medical technology that began with a contracted research project between the Chulalongkorn University Faculty of Veterinary Medicine and a multinational science and technology company. The research team has in-depth knowledge and IP for developing a test kit that can easily test the progesterone level of animals from serum samples. In this research, the industry partner wanted to detect swine progesterone in the form of a strip test as it is a cheap and convenient method for mass adoption. The company promised to license the technology for sales and marketing purposes after the prototype showed promising results.

This research project has a potentially high impact on the local livestock industry. It is a new state-of-the-art technology and is an easy, effective, and low-cost solution that addresses many pain points faced by the swine farm industry. Moreover, we foresaw that the technology could be adapted to detect other hormones and health- or disease-related biomolecules in other livestock, increasing the market size and potential customers in the future. Finally, the initial readiness assessment revealed a TRL of 6 and an IRL of 1.

With our Augmented Stage-Gate framework, as explained in Table 7, and business directions from the industry partner, the project established its market and business strategy and financial analysis. Moreover, the project team also brought in the qualified diagnostic development (QDD) center of Chulalongkorn University to support strip test design and small-scale manufacturing. Furthermore, with continuous iterations of customer validation, the researchers were able to fit the technology to the user's needs and better understand the type of collaboration the industry was looking for. Thus, the team had business matching opportunities and discussed plausible deals with potential customers.

After more than 6 months of fine-tuning all aspects of the innovation, the project had a TRL of 7 and an IRL of 7 with a final prototype and licensed their technology to an international company that will use the kit for real-world applications. With the success of their first deal, the team has leverage to make future deals with other private companies.

Table 7 Augmented Stage-Gate activities for progesterone test kit

Stage 0: innovation ideation	Stage 1: build business case	Stage 2: development	Stage 3: test and validation	Stage 4: launch
• The research team shows promising track record in development progesterone strip test that causes impact to livestock industry • The technology prototype shows a promising result • The technology had a TRL of 6 and IRL of 1 at the time of screening	• The industry partner showed high interest in this research for a swine use case and agreed to fund this project as well as to license out when the prototype showed promising results • Legal document was developed including an NDA • Interview and engage with the industry partner to bring in the idea for setting up research direction • Study the IP landscape to find freedom to operate	• Develop the prototype and then validate the result with the prospect user to see the problem–solution fit • Gauge customer reaction and purchase intent • Engage Chula QDD center for design and manufacturing strip tests in a small batch • Team recruitment • Refine business model • Apply for grants	• Continue development to complete the first commercial version and ready to launch on the field • Work on the technology licensing agreement with the industry partner	• Completed the licensing agreement • Lessons learned and Recommendations used to adjust business models
TRL = 6	TRL = 4	TRL = 5	TRL = 7	TRL = 9
IRL = 1	IRL = 3	IRL = 5	IRL = 6	IRL = 7

The Augmented Stage-Gate Framework was used in these cases to validate the potential for exploitation, validity, market feasibility, and technological feasibility. All projects had low levels of investment readiness and different levels of technological readiness at the time of screening but were all considered deep technologies with high potential for use in their respective industries. The framework helped the teams carry out innovation framework activities, including continuous customer validation, market research, and business plans. All projects underwent a complete transformation after rigorously applying the framework's validation activities, which included developing their MVP, carrying out multiple user validations, and adjusting their product idea and business plan with a network of mentors. In terms of commercial success, ReadMe successfully transformed into a tech startup named Eikonnex AI and secured business deals for commercial use in private companies. Chest X-ray AI Reporter for COVID-19 remained a not-for-profit technology used in King Chulalongkorn Memorial Hospital to detect COVID-19 and other chest X-ray abnormalities. Progesterone Test Kit licensed their technology to an international company. It is shown that the Augmented Stage-Gate Framework effectively transformed research projects into innovative, high-impact, commercialized products and companies.

Past literature has mentioned that traditional Stage-Gate models are not suitable for many of today's businesses due to fast-changing user needs, uncertain market requirements (Cooper & Sommer, 2018), or industry complexity that requires highly iterative cycles and external collaboration (Sommer et al., 2015) and requires a more flexible and adaptive Stage-Gate model such as integrating agile process (Cocchi et al., 2021). Case studies leveraging these models were mostly conducted in corporates in developed economies. Directly adopting successful models from developed countries' academic institutions require a well-established technology transfer office (Ravi & Janodia, 2022b). Other studies that focus on the academic context in developing countries made suggestions in the policy level, recommending that the government encourage technology transfer by connecting industry and academia (Kirby & El Hadidi, 2019; Ravi & Janodia, 2022b). None has given practical, step-by-step guideline model for technology initiated from academic institutions like ours.

Therefore, our work provides the first proved example of a new product development model that can be applied in similar contexts—commercializing university technology in an emerging economy. It solves the problems that persist in developing countries, Thailand especially, of lack of literature, lack of evaluation from key stakeholders, and a design-actuality gap (Abbasi et al., 2022; Heeks, 2002; Kalyanasundaram et al., 2021; Ravi & Janodia, 2022a). However, we believe this model can also be applied to ecosystems with better infrastructure and maturity. Once research can be stably commercialized, building a strong infrastructure for technology transfer office like those in developed countries is a task recommended in the long run.

Lastly, even though the result from these case studies can confirm the validity of the proposed NPD model, it is not a hundred percent guarantee of successful exploitation. There might be other factors or circumstances that can affect the result such as market or technology that is highly regulated by local law, certain requirements of entrepreneur characteristics, appropriate timing for market or technology readiness, ecosystem or infrastructure that is required for research to commercial process, especially in emerging markets that might have no mature standard yet, etc. Those mentioned can be considered for future research.

Conclusion

Theoretical implications

This study develops a modified NPD framework that incorporates agile, lean startup, and design thinking to the Stage-Gate model for effective research to commercialization process generated from within the university in developing markets. Using the proposed Augmented Stage-Gate framework that has six stages (Innovation Ideation, Build Business Case, Development, Test and Validation, Launch, and Scale-up), we have presented three case studies from the Chulalongkorn University Technology Center. The approach is structural and based on critical thinking, which helps the technology incubator to accelerate the idea-to-launch process, decide the Go/No-Go of each innovation project stage to prioritize resource contribution, and reduce the risk of failure. Applying an open innovation concept can be beneficial during the NPD process of exchanging internal and external ideas. For example, introducing market demand to guide the direction of research, bringing in high-quality human resources from outside firms to accelerate the research and development, engaging users or customers to trial the product at an early stage, and co-creating the sandbox area to test and validate the innovation. Nevertheless, the project team must have an open mindset and absorptive capability to capture the value of this approach. In addition, university or business incubators should engage legal experts to supervise each activity to avoid conflicts of interest with external parties.

Managerial implications

The actual journey from idea to launch can be different from project to project. Engaging the Next-generation Stage-Gate's Triple A System, (Adaptive, Agile and Accelerated) and Agile development to the NPD process is very important. Especially during early stages, each project team should focus on setting up a problem statement and then experimenting to learn and fail early, fast, and cheaply. Additionally, we summarized the key lessons learned during the first few batches of the UTC incubation program. First, the importance of the stage-gate committee role and organization as they are the gatekeepers in deciding the Go/No-Go of each project's stage. The team needs to understand each project very well and be able to effectively track development progress and milestones. Project management software tools can be helpful in sharing ideas and tracking progress among teams, mentors, and committees whose roles must be considered carefully. Second, the incubator is usually responsible for providing NPD guidelines and mentoring for each stage; yet the incubator must also sometimes play a hands-on role solving issues by working closely with each team, especially for topics that they are unfamiliar with or that are at high risk such as regulatory and IP issues. Third, especially during the COVID-19 pandemic period, many activities were conducted online, such as business matching, mentoring, and customer meetings. Online activities lack many of the emotional and social aspects of work done in person. Therefore, the community manager had to work hard to build a supportive environment, maintain momentum and create positive team dynamics. Still, our experience suggests that it is possible to practice a hybrid onsite/online model while maintaining social distancing during the COVID-19 period. Fourth, legal considerations such as NDAs (Non-disclosure Agreements) and co-founder agreements should be considered as early as possible to avoid any conflicts that could cause project delay or failure. Finally, creating an environment where research, business partners, investors, and mentors can get to know each other is very important. These relationships can be developed informally and can lead to successful business deals. However, tech incubators should be able to identify, understand, and manage the expectations and relationships of each party before organizing networking events so that win–win situations can be realized.

Ideas for future research

Further research on the deep-tech NPD framework applied to specific technologies such as Med Tech that require extraordinary activities or have important limitations is needed. Case studies of successes and failures can be very useful. Challenges involving multiple stakeholders in different development journeys can lead to project failure due to miscommunication, lack of transparency, and a lack of legal knowledge. Thus, integrating legal perspectives and creating legal readiness levels in each NPD journey is essential. Finally, an analysis of co-founder characteristics, such as personality and working style, can suggest suitable ways of commercialization to maximize the probability of success.

Abbreviations

AI	Artificial intelligence
FDA	Food and Drug Administration

GDP	Gross domestic product
GERD	Gross expenditure on R&D
GMP	Good manufacturing practice
IP	Intellectual property
IRB	Institutional review board
IRL	Investment readiness level
MVP	Minimal viable product
NASA	National Aeronautics and Space Administration
NDA	Non-disclosure agreement
NPD	New product development
OCR	Object character recognition
PDPA	Personal Data Protection Act
PESTEL	Politics, economics, social, technology, environment and legal
QDD	Qualified diagnostic development
SWOT	Strength, weakness, opportunity, and threat
TAM	Technology acceptance model
TRL	Technology readiness level
TTO	Technology transfer office
UI	User interface
UTC	Chulalongkorn University Technology Center
UX	User experience

Acknowledgements
The authors would like to thank Eikonnex AI Co., Ltd., Chulalongkorn University Center for Artificial Intelligence in Medicine (CU-AIM), Chulalongkorn University Center of Excellence in Swine Reproduction, and Qualified Diagnostic Development (QDD) Center of Chulalongkorn University for assisting the required information and being used in the selected case studies. We would like to express our gratitude to the Second Century Fund (C2F) of Chulalongkorn University and the Program Management Unit for National Competitiveness Enhancement (PMU-C) of The Office of National Higher Education Science Research and Innovation Policy Council (NXPO) to support this research project. Lastly, we would like to thank the staffs of UTC, which now forms a research group called Ignite Innovation Lab.

Author contributions
PK, PD, and SK conceived the concept of new product development and entrepreneurship for academic research and technology transfer. PT wrote the manuscript. AA collected data from each research team and the publication templating.

Funding
Second Century Fund (C2F) of Chulalongkorn University and the Program Management Unit for National Competitiveness Enhancement (PMU-C) of The Office of National Higher Education Science Research and Innovation Policy Council (NXPO) to support this research project.

Availability of data and materials
Not applicable.

Declarations

Competing interests
The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Received: 8 November 2022 Accepted: 16 June 2023
Published online: 17 July 2023

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