MINISTRY OF INDUSTRY
SCIENCE, TECHNOLOGY & INNOVATION

NATIONAL INSTITUTE OF SCIENCE,
TECHNOLOGY AND INNOVATION

STI Focus

SCIENCE, TECHNOLOGY AND INNOVATION

Issue 01/2022 - June 2022

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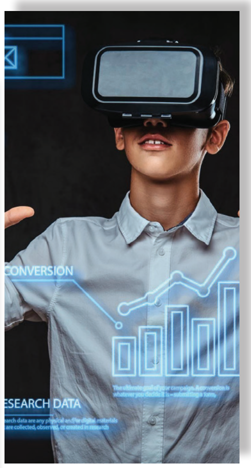

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FOREWORD

Science, Technology, and Innovation (STI) have been globally recognized as a core value of economic growth, industrial development, sustainable development, and social resilience. Evidenced from its half-decade implementation of its Industrial Development Policy (IDP) 2015-2025, Cambodia needs to redirect its national policies. The redirection is to respond to the Fourth Industrial Revolution. In response to this need, Cambodia adopted its National Science, Technology and Innovation (STI) Policy 2020-2030 in 2020 and Digital Government Policy 2022-2035 in 2022. Cambodia expects that the effective implementation of these policies will shift its economic development, diversify its economy, and connects its development trends with other developed economies.

To satisfy the expectation, the Ministry of Industry, Science, Technology & Innovation (MISTI) was established in 2020. Two new institutions were introduced under MISTI. The institutions are commissioned to provide policy inputs and research-based evidence in Industry, Science, Technology, and Innovation. The two institutions are (1) the General Directorate of Science, Technology, and Innovation (GD/STI) and (2) the National Institute of Science, Technology, and Innovation (NISTI). Under NISTI, the Department of Science, Technology and Innovation Promotion and Development (D/PRO) has its mandate to promote public awareness of Science, Technology, and Innovation. Building trust, creating synergy, and promoting public awareness in Science, Technology, and Innovation depend on research-based knowledge. The research-based knowledge in Science, Technology, and Innovation is a key to transformation, creativity, and Innovation. Building trust, creating synergy, and promoting public awareness requires the mutual acquisition of knowledge between scientists and the public. The knowledge needs to communicate through channels that share constructive perspectives. NISTI established STI Magazine to serve this purpose and link scientists with the public.

I believe that the establishment of STI magazine could effectively contribute to the inculcation and enhancement of STI knowledge in society. By using this STI magazine platform, scientists can communicate their research findings, practical methodology, or innovative process, which can be adopted to improve small and mid-size enterprises SMEs productivity, to name a few, to the public. The papers' publication in the STI magazine broadly covers the topics in the area of scientific findings, technology trends, STI policy, and STI career.

I would like to take this opportunity to express my sincere thanks to the National Institute of Science, Technology, and Innovation (NISTI) and all individual members involved in initiating and creating this STI magazine. I sincerely hope that the STI magazine could engage more scientists and help boost the promotion of STI and STEM education and careers in Cambodia.

Phnom Penh, 22 June 2022

Senior Minister

Minister of Industry, Science, Technology & Innovation

***Kitti Settha Pandita* CHAM Prasidh**

EDITORIAL NOTE

On behalf of the editorial team, we are very grateful to introduce to our readers an inaugural issue of Science, Technology, and Innovation (STI) Magazine. This magazine is initiated and managed by National Institute of Science, Technology and Innovation (NISTI), a general department under Ministry of Science, Technology & Innovation (MISTI) as the first STI Magazine published in Cambodia. The publication of the STI Magazine is established under three core objectives: 1). to establish an STI Magazine as a medium of publication communication of Science, 2). to disseminate the scientific finding, technology trends, and STI policy, and 3). to promote STEM education and careers in Cambodia.

The first issue of STI Magazine is a stepping stone and network of communication that helps to deliver and wide-spread STI information across the country covering 1). Scientific findings, 2). Technology trends, STI-related policy, and 3). STEM education and careers. The majority of articles published within this issue are masterpieces from local entrepreneurs and scientists and have significant impacts on STI in Cambodia. NISTI in collaboration with the public and private sectors works to form an editorial team that consists of experts from different fields of expertise. Members of the editorial team who contributed to this work have invested time and effort in formulating and compiling STI information and masterpieces from Cambodian entrepreneurs and scientists. To achieve the objectives of STI Magazine, the editorial members created an editorial process to monitor the publication of STI Magazine. Each work included in the STI Magazine was thoroughly selected and reviewed by editors and reviewers to guarantee a good quality publication with well-structured, coherent, objectiveness, ethical conduct, and especially the result that beneficial to the reader as a whole. Thanks are due to each editorial member, and especially NISTI for initiating and leading the project. A sincere appreciation, credit, and thanks are also given to MISTI for supporting this project from the start until today.

We sincerely hope that our first volume of the magazine could help to nourish the readers' knowledge and mindset in STI and help them to prepare for the evolution of STI and its adaptation.

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Scientific Findings

01 SHELF-LIFE EVALUATION OF METHANOL TEST KIT DEVELOPED BY A COLORIMETRIC METHOD

Ms. VA Sreythea
Bachelor degree in Food Chemistry, International University, Cambodia

Ms. KONG Sopheaktra
Bachelor degree in Food Chemistry, International University, Cambodia

Mr. CHONG Arechkang
Bachelor degree in Food Chemistry, International University, Cambodia

Ms. VANN Kimroeun
Master degree in Industrial Biotechnology, Khon Kaen University, Thailand

Dr. PHAN Kongkea
PhD in Environmental Science and Engineering, Gwangju Institute of Science and Technology, Republic of Korea

Executive summary

This study aimed to develop a simple field test kit and evaluate its efficiency for rapid screening for deteriorated methanol concentration in suspected alcoholic drinks and beverages. The test kit was designed based on a colorimetric method using basic fuchsin following the oxidation of methanol in a sample matrix. This simple test kit was evaluated by different methanol impurities such as distilled water, 5, 10, 20, 40, and 60% (v/v) ethanol. This study showed that the detection sensitivity of 10, 20, and 40% ethanol solution was well achieved, as the relatively low concentrations of methanol in the range of 0 to 0.15% (v/v) could be distinguished by its visible color. Moreover, the stable shelf life of the reactions was 24, 15, and 11 days for methanol contamination in 10, 20, and 40% ethanol solutions, respectively. This study suggested that this simple field test kit should be handy and practical for the rapid detection of lethal methanol concentration in alcoholic products in Cambodia.

Keywords: *Methanol, shelf-life, alcohol, colorimetric method*

1. Introduction

Methanol (CH_3OH) or methyl alcohol is a toxic, colorless, flammable liquid and has an odor similar to ethanol. Due to its cost-effectiveness and ease of accessibility, methanol has been used to degrade alcoholic beverages and wines. Recently, this fraudulent behavior has led to either death or blindness of many people in some developing countries due to the lack of power in the alcohol quality process (Hassanian-Moghaddam & Zamani, 2016; Hovda, Mcmartin, & Jacobsen, 2017). The contamination of this toxic alcohol also comes from homemade production as the production method has been passed down from generation to generation for years. The ethanol production from the traditional/informal method is popularly distributed in rural areas in a large quantity and at a cheap price without government control. This increases the chemicals hazardous in ethanol, the most important of which is methanol, and this may come from the secondary metabolic product of mixed microorganisms (yeast, mold, and bacteria) that are used mainly for rice fermentation (Ohimain, 2016). Both unsupervised production of alcoholic beverages and the lack of quality assessment during production increase the risk of contamination of the produced alcohol with undesirable toxic components, including methanol. Therefore, during the process of quality control of the production of such beverages, it is vitally important to be able to determine the presence of sufficient methanol concentration that can lead to poisoning.

In Cambodia, liquid with a methanol content of 0.15% (v/v) methanol or more is not legally considered a safe alcoholic beverage (Matsukawa, 2017). The police officers request the determination of methanol concentration when they find evidence indicating the suspected consumption of alcoholic beverages. For example, on June 3rd, 2021, the MOH Cambodia reported that methanol was detected in high concentrations in the wine of victims, resulting in 31 deaths and several dozen hospitalizations in Kandal, Kampot, and Pursat provinces (MOH, 2021). The standard method for determining the methanol content in alcoholic beverages is Gas Chromatography (GC). However, this technique is expensive and requires for considerable knowledge and experience and is not readily available in many laboratories in developing countries (Caruso et al., 2011). The access to a safe, cheap and simple method to prove the absence of illicit methanol before ingestion is highly advantageous. This study aimed to apply a test kit to determine the concentration of methanol in distilled water and different percentages of liquid alcohol (ethanol) by a visual color change and evaluate its stability shelf life.

2. Materials and methods

The method of methanol determination was carried out by modifying a method described by Matsukawa (2017). The 1 ml of solution A was measured and transferred to the glass tube containing 0.25 ml of the sample. After 10 min, 0.4 ml of solution B was added into the mixture solution and then mixed it well. The solution C (1.5 ml) was immediately dropped into the glass tube when the color of the mixture solution changed to clear. The reaction time was recorded when the color of solution changed at 2, 3, 5, 10, 15, 20, 30, 40, 50, and 60 min.

3. Result and discussion

3.1. The determination of methanol contamination in distilled water and various ethanol contents

The present study has shown that this colorimetric method does not apply to distilled water and 5% (v/v) ethanol contaminated with 0-1% (v/v) of methanol concentration. These samples (distilled water and 5% (v/v) ethanol) had high water content, so that the water present could interfere with the reaction of the solution A. In contrast, these methanol contaminations (0-1%, v/v) in 10, 20, and 40% (v/v) ethanol were easily recognized the difference by visual observation. The color of each reaction developed slightly and became stable 30 min after adding the solution C. The methanol impurities in 10, 20, and 40% ethanol were detectable the differences by the naked eye even though the concentration of methanol was 0%. After adding solution C, the mixture solution has turned their color to pale yellow, dark black, pale violet, violet, violet+2, dark violet, and dark violet with the methanol concentration of 0, 0.05, 0.1, 0.15, 0.25, 0.5 and 1% in 10% ethanol, respectively. On the other hand, the color reaction of 20% and 40% ethanol has developed slightly slower than 10% ethanol, but it is not quite different in color production after 30 min. This study reported that the higher methanol content would provide a faster visual change and more purple color development, as shown in Figure 1.

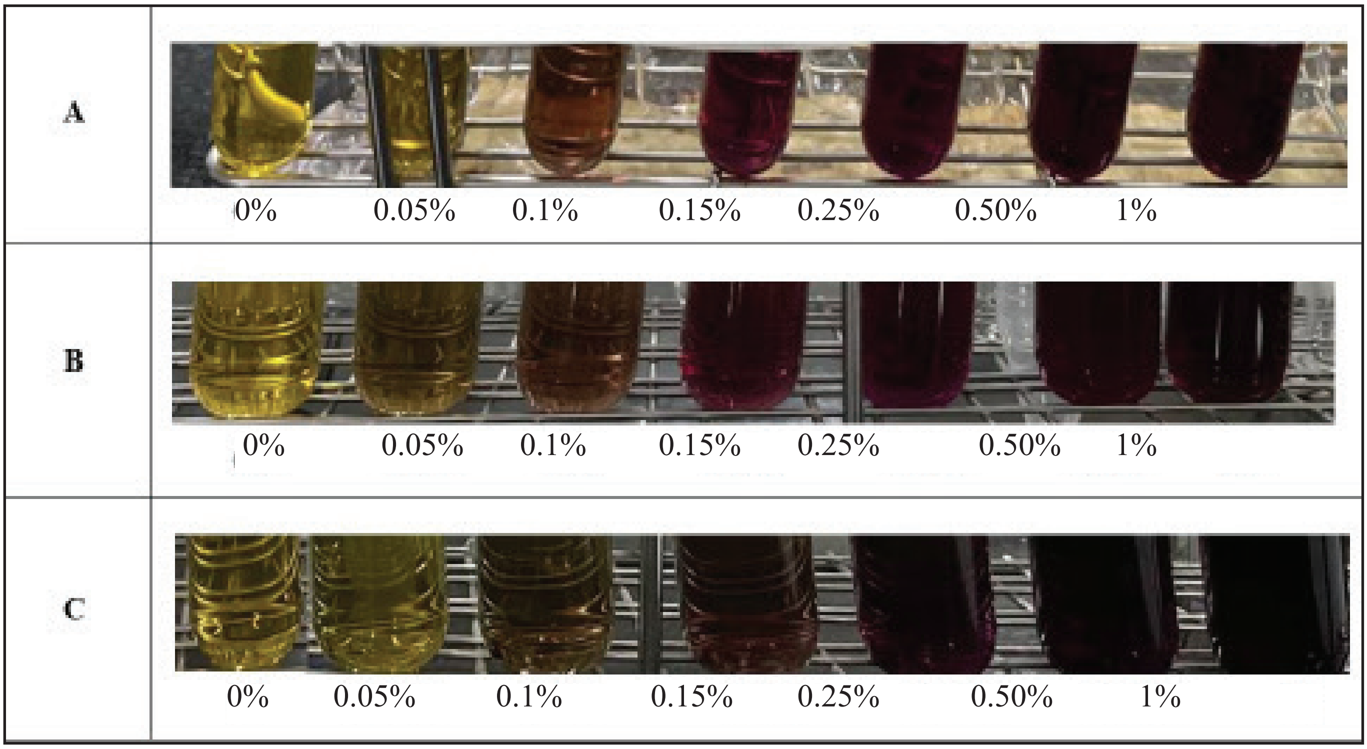

Figure 1. The color productions of different methanol contamination in different ethanol percentage after 30 min. A, B, and C referred to the methanol contamination in 10, 20, and 40% ethanol, respectively.

However, color production could be affected if the ethanol concentration increases. The color production was related to the production of acetaldehyde produced when ethanol was oxidized by solution A (Pourkarim et al., 2021; Felix & Ajibade, 2018; Li, Mo, & Gao, 2018). In the practice, this study showed that the reagents in the current method were not suitable for the determining of methanol contaminations in 60% ethanol in the smallest amount because the color development of 0.05, 0.1, and 0.15% was not significantly different, as shown in Figure 2. The methanol content of 0.05, 0.1, and 0.15% in 60% ethanol could be easily confused because these three methanol concentrations have turned the same color of pale black after adding the final solution.

Therefore, based on the naked eye observation, the different concentrations of methanol contamination in 10, 20 and 40% ethanol provided good conditions for formaldehyde production by solution A ($KMnO_4$) compared to others. Moreover, these three ethanol concentrations were also selected to study the stability of the chemical solutions in the next experiments.

Figure 2. The color productions of different methanol contamination in 60% (v/v) ethanol.

3.2. Self-life evaluation of methanol reagents

After observing the reaction of methanol contaminations in 10, 20, and 40% ethanol for 24 days, the experimental results showed that the methanol reagents used with 10% ethanol had the most extended shelf life. The color generation in the reaction with 10, 20, and 40% ethanol worked smoothly and was stable for 24, 15, and 11 days, respectively. The detection sensitivity of methanol in 10% ethanol did not change after 24 days because the mixture of ethanol and methanol in this reaction had low ethanol content. In contrast, the shelf life of mixture solutions derived from 20 and 40% ethanol was shorter than that of 10% ethanol as the ethanol content of these mixtures was two and four times higher than 10% ethanol, respectively. Therefore, the shelf life of methanol reagents was last depended on the amount of ethanol content that was contaminated with methanol. The higher ethanol concentration would provide a shorter shelf life due to the interference of acetaldehyde production from ethanol oxidation.

4. Conclusion

The methanol field test kit has been successfully developed based on a colorimetric method. The result of this study revealed that low methanol contaminations in 10, 20, and 40% ethanol solutions were found to be detected well with the developed methanol test kit by visible color changes within 30 min after adding the final reagent. The shelf life of this method was stable for 24, 15, and 11 days of methanol contamination in 10, 20, and 40% ethanol, respectively. Moreover, the application of this methanol test kit is practical, fast, simple, safe, cheap, and reliable in detecting the toxicity concentration of methanol content in suspected alcoholic drinks and beverages.

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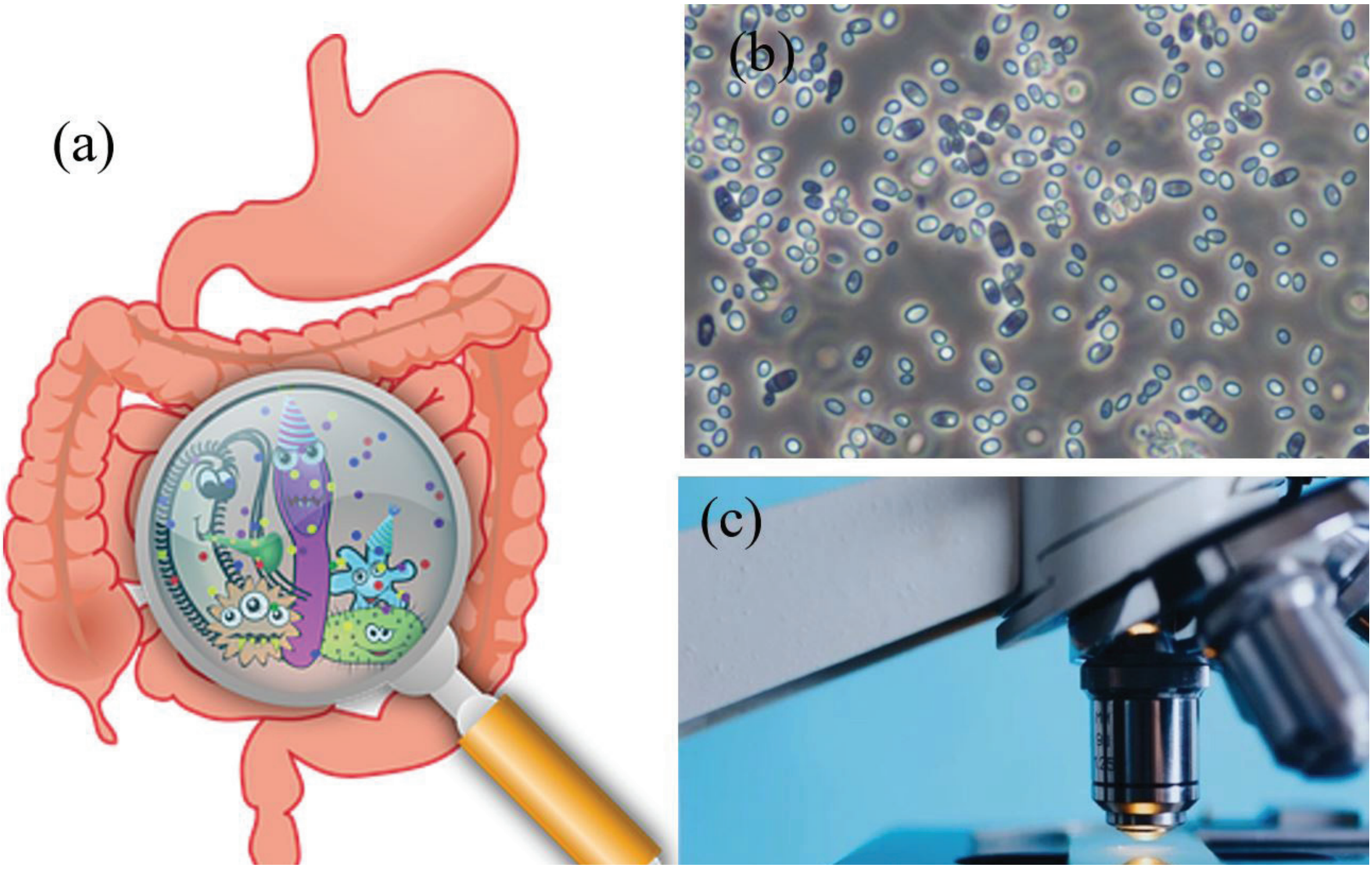

Figure 1. Microbe under microscope. (a) microbes in human intestine, (b) microbe under microscope, (c) microscope.

02 INTRODUCTION TO MICROBIOLOGY

Dr. UNG Porsry
PhD in Bio-Engineering, Tokyo Institute of Technology, Japan

1. Microbial history

Microbes exist around us, but we just cannot see them with our eyes. The life of microbes started and dominated the earth about 3.8 million years ago before the birth of human life. This study showed their long-term co-evaluation and found that the genome of microbes consists of around 65% in the human genome. Moreover, a portion of microbes that exist in our digested system, known as microbiota, does co-evolve with us and role in regulating the function of our body, and they're essential for our life (Figure 1). For instance, there are around 10 microorganisms in every human cell. *Firmicutes* and *Bacteroidetes* are the phyla that are generally dominant in the human gut; however, diet, lifestyle, behavior, and medical treatment do affect and shape the microbiota in the human gut. (Rook et al., 2017; Stark, 2010).

2. Role of benefitial microbes

The world is driven by microbes. The essential elements for life on the earth were produced by microbial communities' activities including oxygen, nitrogen, carbon, etc. Almost haft of the photosynthesis was done under the microbial activities, which is the role in lower carbon dioxide and increasing the amount of oxygen in the atmosphere. Microorganisms play a crucial role in our body, such digested system and immune system, and they are high benefits for humans in term of food, nutrient, and vaccine production (Stark, 2010). You may probably don't know that most of the food we daily consume, such as fermented cucumber, soybean fermented, fish sauce, yogurt, cheese, ethanol, beer, wine, etc., that are made by microorganisms (Figure 2).

Microorganism does essentially for life; however, the word of microorganism is somehow reverting as a negative impression from the public since some of them may suffer from microbial disease or hear about the adverse effect of microbes.

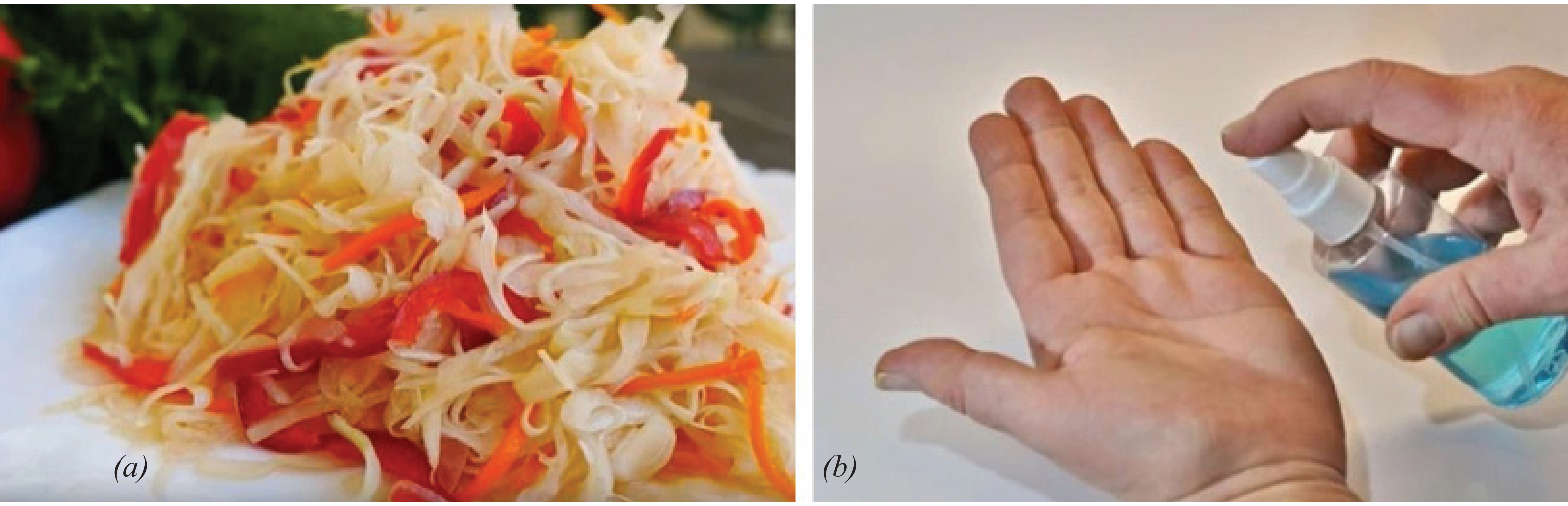

Figure 2. Product derived from microbial's activities. (a) fermented food, (b) hand sanitizer (ethanol base).

3. Microbial diseases

Microbial diseases have put numerous pressures and threaten human health, animal health, and global stability. The diseases derived from bacteria were generally treated by the different way of the medical drugs including antibiotics, while the outbreak of virus-related diseases has acted by the development of vaccines. The speed of disease spreading relates to many factors such as demographic trends, high-density population, human mobility, transportation service, and inadequate health service (Figure 3). For instance, the virus outbreak of SARS-CoV-2 has given the negative impact on the world economy and social within the unknown source, high transmission rate, and mutation. It leads to high mortality ever in the elderly and those who have weak immunity system. All countries make efforts in emergency responses such as imposing the obligation to wear masks, social distancing, travel restrictions, and city lockdown. However, the number of Covid-19 infections is still high. From the privileged experience of the pandemic in the world, the production of vaccines is necessary to combat the outbreak (Excler et al., 2021).

Figure 3. Water around the floating house was contaminated by human waste. (a) floating house at Tonle Sap Lake, (b) colonies grow on Chromocult agar: E. coli (purple), coliform (pink), others (white).

4. Microbial community in Tonle Sap lake

The importance of microbe role in nutrient recycling in freshwater was highlighted in the 1940s, and subsequently, their role in the global carbon budget balancing was acknowledged. However, the distribution of microbial consortia in the environment, revealed by molecular biology, may depend on its geography, environmental condition, and human activities (Newton et al., 2011).

Tonle Sap Lake, which is located in a tropical climate in Cambodia, is known as a unique flood-pulsed ecosystem and the largest body of freshwater in Southeast Asia. This lake covers an area of 2,500 km^2 during the dry season and expands up to 16,000 km^2 during the rainy season, serving many benefits for life and the environmental ecosystem (Brooks et al., 2007; Holtgrieve et al., 2013). The study revealed differences in the relative abundance of different members of the microbial consortia between lake water and lake sediment (Figure 4). According to the Miseq sequencing analysis, a high abundance of *Actinobacteria, Proteobacteria, Cyanobacteria,* and *Bacterroidetes* were found in water samples. In contrast, the high abundance of *Firmicutes, Chloroflexi, Actinobacteria,* and *Proteobacteria* were abundance in sediment samples. The finding was reasonable since most of the dominant bacteria found in the water were aerobic bacteria, while the bacteria found in high abundance in the sediment are anaerobic bacteria. The concrete result showed that the relative abundance of the microbial consortia near floating villages was different from those measured at non-point sources. The human waste may strongly influence the water environment near floating villages since the villagers usually defecate and urinate directly into the lake (Ung et al., 2019).

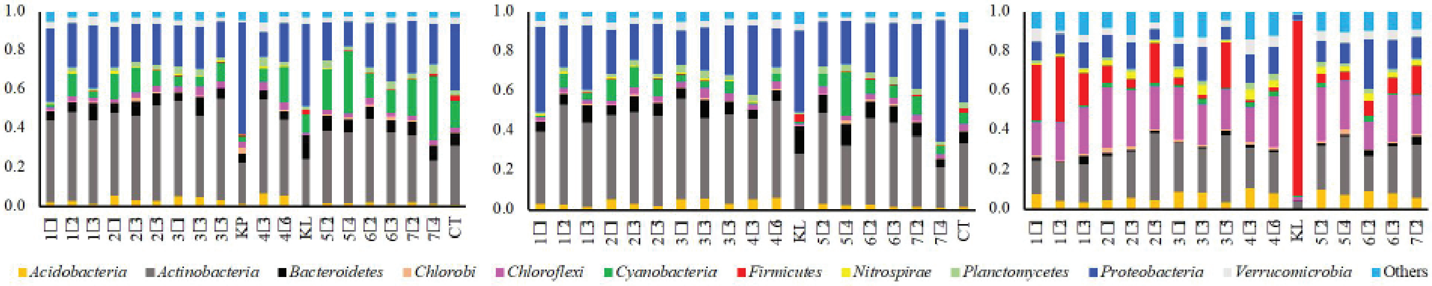

Figure 4. Relative abundance of bacterial phyla in the surface water, deep water, and sediment samples in Aug-2017, Tonle Sap lake. TF: Tropical Forest, KP: Kampong Plouk, KL: Kampong Luong, and CT: Chhnok Tru floating village.

5. Summary

Life does rely on the microbes; without microbes, life does not exist. We better understand more about the beneficial microbes; however, we also never forget to have good hygiene and away from harmful microbes which may cause the disease to us.

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03 MORPHOLOGICAL METHOD FOR THE IDENTIFICATION OF *BEAUVERIA* ISOLATES

Mr. SOTH Sereyboth

Master degree in horticultural science, Lincoln University, New Zealand

Executive summary

Beauveria is a genus of entomopathogenic fungi that exhibits traits suitable for the development of commercial biopesticide products to control various arthropod pests, as well as plant pathogens. The colony and conidial morphology were the two main features used for morphological identification. The growing cultures were white to pale yellow (isolates from *B. bassiana* and *B. pseudobassiana*) and pink to red (isolate from *B. caledonica* and *B. malawiensis*). Morphological identification can be used to identify some *Beauveria* isolates.

Keywords: *Beauveria, entomopathogenic fungi, identification, morphology*

1. Introduction

Among entomopathogenic fungi, the genus *Beauveria* (Balsamo) Vuillemin is recognized as the most important fungal genus for controlling a wide range of agricultural, veterinary, and forestry arthropod pests (Mascarin & Jaronski, 2016). *Beauveria* has a cosmopolitan distribution, a simple life cycle, and a broad host range of more than 700 susceptible invertebrate species (Rehner & Buckley, 2005). The market share of *Beauveria*-based products is forecasted to value at around USD 780 million by 2028 (DataBridge, 2021). Food safety is a significant problem in Cambodia due to the high pressure of alien pests and plant pathogens, forcing farmers to use predominantly chemical pesticides (Srinivasan, 2018). Thus, isolation *Beauveria* isolates in Cambodia to develop new biopesticides to be used as an alternative to synthetic pesticides. However, the identification of this fungal genus is complicated and is required expertise in both morphological and molecular methods.

Morphological identification is used to distinguish individual species of Beauveria using a light microscope at high magnification to compare vegetative and reproductive characteristics (Raad, 2016). The most important morphological feature used to distinguish between species of *Beauveria* are their asexual spores or conidia (Cummings, 2009). The shape and size of these conidia can be assessed at 400x magnification after culturing the fungus on PDA (Glare et al., 2008). Therefore, this paper showed some species of *Beauveria* identification based on morphological characteristics, which is used for future studies in Cambodia, such as *Beauveria* identification key and the important of this fungal genus.

2. Material and methods

2.1. Sources of isolates

Six isolates of *Beauveria* spp. derived from New Zealand habitats were investigated (Table 1w).

Table 1. The species identities of the 14 Beauveria isolates used in this phylogenetic study.

Isolate	Habitat/Host	Originated from	Isolated by
J2	*Plutella xylostella*	BPRC growing chamber	Jenny Brookes
CTL20	*P. xylostella larva*	BPRC growing chamber	Jenny Brookes
F532	*Hylastes ater*	Riverhead	Travis Glare
Bweta	*Hemideina femorata*	Westland	Jenny Brookes
I12 Damo	*Coccinella undecimpunctata*	Lincoln University	Damien Bienkowski
FRhp	Lab contaminant	Lincoln Universiwty	Sereyboth Soth

2.2. Purification and indentification method

a. Single-spore culture

For the single-spore culture of all isolates, the method of Mwamburi (2016) was followed. In summary, potato dextrose agar (PDA) (Oxoid) was used as a growth medium for the fungal purification process. A sterile metal needle was used to transfer single-spores of each isolate to fresh PDA. All culture plates were incubated at 23^{o}C ± 1^{o}C with a photoperiod of 12:12 D/L for 14 days at which time conidia were collected for long-term storage at -80^{o}C.

b. Morphological characteristics

At 14 days of growth, each Petri plate's upper and bottom sides containing the cultured fungi were photographed using a Canon camera (PowerShot G2). A metal loop was used to transfer conidia from a plate onto a glass microscope slide, stained with 10 µL of cotton blue dye (diluted 1:1 with dH^{2}O) and observed under an optical microscope, Leica DM2500 with cellSens software (Olympus) at 20x and 50x magnification. The length and width of three random spores were determined using the measurement function within the software (Figure 1).

3. Results

The colonies of the six *Beauveria* isolates were white to pale yellow or pink to red color. While the isolates J2, FRhp, I12 Damo, and CTL20 were fluffy white on the upper plate, they were pale yellow when viewed from the base of the Petri plate. For the isolate F532, both sides of the Petri plate were white, while the isolate Bweta was pink on the top and slightly red on the bottom. The conidia ranged in shape from globose, subglobose, or broadly ellipsoid for isolate J2, FRhp, I12 Damo, and CTL20 to ellipsoid, oblong, or cylindrical for isolate F532 and isolate Bweta (Figure 1). The conidial sizes ranged from 2.40 to 2.57 µm in length and 1.94µm to 2.07 µm in width (average 2.48 x 2.01) with a ratio (length/width) of 1.24 µm for isolates J2 and CTL20. Relatively similar to these isolates, the size of conidia of isolates FRhp and I12 Damo ranged from 2.07 to 2.27 µm in length and 1.8 µm in width (average 2.16 x 1.8 µm). The isolate F532 had, comparatively, quite big conidia, 3.6 µm in length and 2.14 µm in width, with a ratio of 1.68 µm. The conidia of isolate Bweta were larger than all the other isolates in the study and measured 3.8 µm in length and 2.00 µm in width with a ratio of 1.90 µm (Table 2).

Table 2. Conidial size (the average of three spores) of the six Beauveria isolates measured using an optical microscope Leica DM2500.

Isolate	Length (µm)	Width (µm)	Ratio L/W (µm)
B. bassiana J2	2.57	2.07	1.24
B. bassiana CTL20	2.40	1.94	1.24
B. caledonica F532	3.60	2.14	1.68
B. malawiensis Bweta	3.80	2.00	1.94
B. pseudobassiana I12 Damo	2.27	1.80	1.26
B. pseudobassiana FRhp	2.07	1.80	1.15

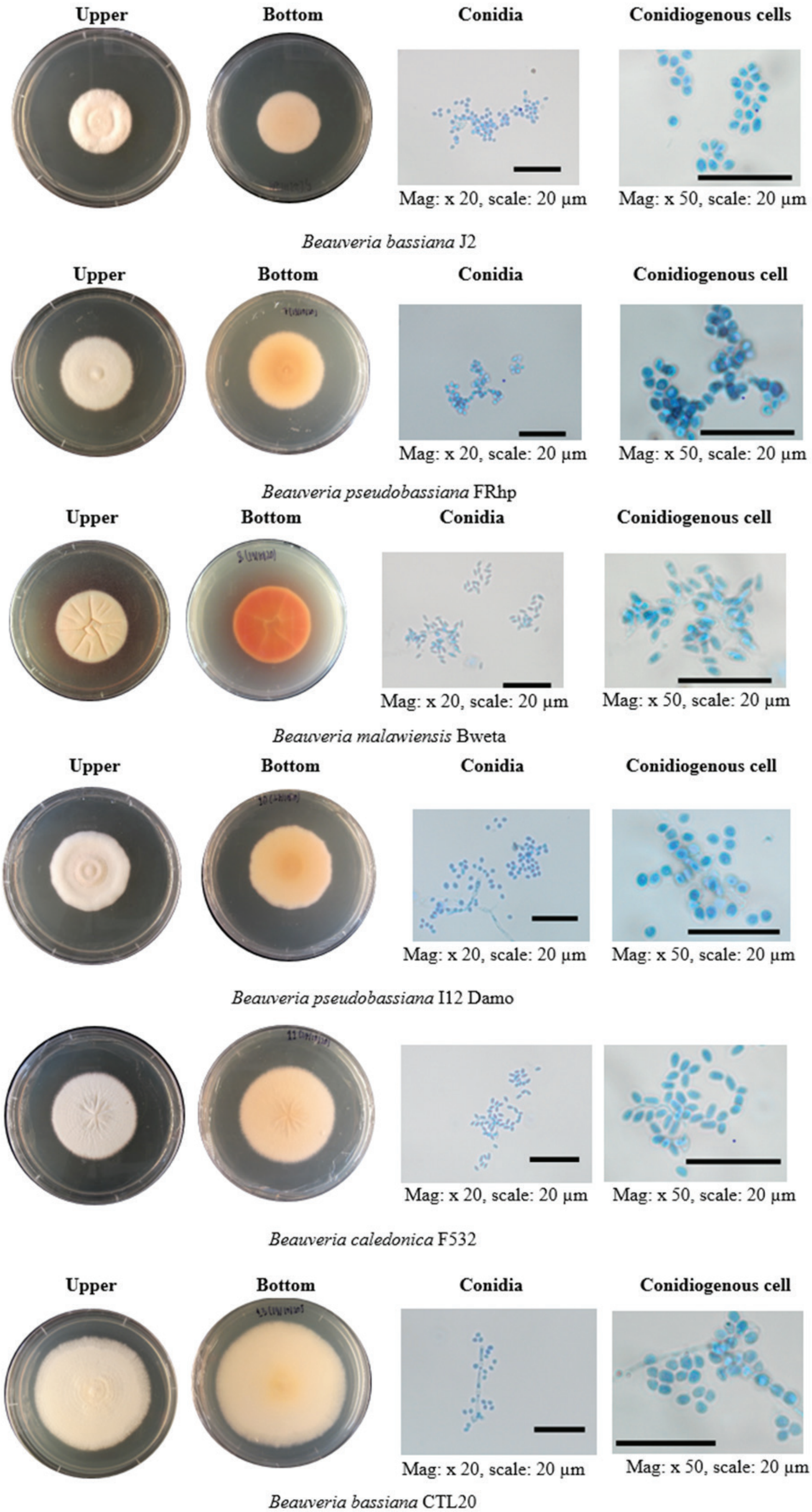

Figure 1. Colonies and conidia of all six Beauveria isolates utilized in this study (after incubation at 23^{o}C ± 1^{o}C on PDA within a photoperiod of 12:12 D:L for 14 days) staining using blue cotton dye.

4. Conclusion

Six isolates used in this study were from four *Beauveria* species (*B. bassiana, B. pseudobassiana, B. caledonica,* and *B. malawiensis*). The colonies of the six *Beauveria* isolates ranged in color from white to pale yellow and pink to red, while their conidial shapes ranged from globose, subglobose to broadly ellipsoid to ellipsoid, oblong or cylindrical. The conidial sizes ranged from 2.48 x 2.01 µm for *B. bassiana*, 2.16 x 1.8 µm for *B. pseudobassiana*, 3.60 x 2.14 µm for *B. caledonica*, and 3.80 x 2.00 µm for *B. malawiensis.* These morphological methods can be used for future identification of *Beauveria* species in Cambodia.

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TECHNOLOGY TRENDS

04 CHARACTERISTICS AND INNITIATIVES OF CAMBODIA'S SMART CITIES IN ASEAN SMART CITY NETWORK

Dr. SIEV Sokly
PhD in Civil and Environmental Engineering, Tokyo Institute of Technology, Japan

Dr. SENG Touch
PhD in Urban and Regional Planning, Khon Kaen University, Thailand

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Executive summary

- The article discusses the concept and characteristics of smart cities in Cambodia.
- Four typologies of a smart city can be categorized based on their function and economic potential, namely regional economic corridors, gateway cities, border cities/towns, and capital cities.
- Through examining the dimensions and focused development areas of smart cities developed by the ASEAN Smart City Network (ASCN), the article finds that Phnom Penh, Battambang, and Siem Reap cities have applied ASCN's definition.
- It is also important to consider city size, economic orientation, geographic location and accessibility, endowments, income levels, history, political systems, institutional capacity, and autonomy in the developing provincial smart city.

The rapid growth of the urban population, cities around the world, including in Cambodia, will need to address the exacerbating problems, including traffic congestion, water, and energy supply shortages, and sewage and waste disposal issues. Furthermore, cities will face the increased intensification of disasters caused by climate change and infectious diseases such as the COVID-19 pandemic. Inhabitants in urban areas will further be challenged due to limited resources and services, including medicine, education, environment, and transportation (Kirimtat et al., 2020). Smart cities have emerged as a solution to address the challenges arising with the exponential growth of urbanization and population. However, the smart city concept is still evolving and not mainstreamed throughout the globe due to technological, economic, and governing barriers.

Therefore, by using the systematic review approach, this article discusses the concept and characteristics of smart cities in Cambodia under the context of the ASEAN Smart City Network (ASCN).

According to the literature reviews, there is a wide range of definitions of a smart city provided by academia and practitioners, who have not been consistently agreed in terms of characteristics, components, technologies and concept of a smart city due to city's local and cultural contexts (Seng et al., 2022). However, the common goals of a smart city are to improve quality of life and promote sustainable growth in society, economy and environment.

Based on the city characteristics and national and regional development strategies, Cambodian cities can be categorized into four typologies based on their function and economic potential, namely regional economic corridors, gateway cities, border cities/towns, and capital city (World Bank, 2018). Regional economic corridors serve critical roles in regional economic development and integration. Gateway cities serve as a primary entry point or "gateway" to the country or region. Gateway cities often have an international or domestic hub airport or seaport serving as the primary arrival and departure point and serves as an anchor/center for regional economies. Strategically located along economic corridors, in most cases, border cities/towns may have various roles of serving as a gateway for cross-border trade and tourism as well as Border Economic Zones (BEZ) to facilitate production and trade across borders. Finally, capital cities are cities that serve as the primary economic, cultural, and intellectual centers of a nation (World Bank, 2018).

Being one of the members of ASCN, Cambodia has adopted ASCN's smart city definition as the city that promotes economic and social development alongside environmental protection through effective mechanisms to meet the current and future challenges of its people while leaving no one behind (ASEAN Secretariat, 2018). Cambodia has selected three cities, Phnom Penh, Battambang, and Siem Reap, as pilot cities to participate in the ASCN among the 26 ASEAN cities in 2018 to provide sustainable green growth and encourage healthy economic activities that reduce the burden on the environment while improving the quality of life (Pen, 2019). These cities have mainly focused on four key development areas such as civic and social, quality environment, built infrastructure, and safety and security, and their typology, vision, and initiative projects are summarized in Table 1 below.

Table 1. Summary of action plans of Cambodia's pilot smart cities participating in ASCN.

City	Vision	Development Focus Area	Smart City Projects
Phnom Penh (Capital city, gateway city)	To improve the urban environment to enhance citizen's quality of life	• Built infrastructure • Quality environment • Civic and social	• 11 Sidewalks Rejuvenation Project • Improving the efficiency of Phnom Penh Public Transit
Siem Reap (Provincial city, gateway city)	Siem Reap is a beautiful, unique and ideal tourist destination, characterised by the harmony of Khmer history, arts, and nature.	• Civic and social • Safety and security • Quality environment	• Smart Tourist Management System • Solid waste and Wastewater Management
Battambang (provincial city, regional economic corridor city)	To achieve a socially responsible, environmentally friendly, and economically successful city whilst Retaining Battambang's unique character.	• Civic and social • Quality environment • Built infrastructure	• Urban Street and Public Space Management • Solid and Liquid Waste Management

In short, these key development areas selected to be designed and implemented in Phnom Penh, Siem Reap, and Battambang cities based on their natural characteristics, potentials, and varieties of conditions and needs, and contexts of technologies. Meanwhile, two other development focus areas, including the health and well-being of people and industry and innovation, have not been considered for the pilot smart city development yet. Therefore, for future study, key elements/components should be considered for the local context in Cambodia, including inclusive dimensions of smart city, national and sub-national smart city committees, strengthening R&D and innovation for smart city, human resource development and participatory procedure of smart city development.

As the development perspectives, most cities in Cambodia have their own set of development concerns based on their distinct characteristics, challenges and functions (vision and objectives). Therefore, it is important to consider other dimensions (World Bank, 2018), including city size (population, area, density, etc.), economic orientation (industries and services), geographic location and accessibility (coastal, inland, land-locked, etc.), endowments (resource-rich or barren), income levels, history (new, old, planned, unplanned), political systems, institutional capacity and autonomy.

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05 VIRTUAL REALITY APPLICATION IN CIVIL ENGINEERING LABORATORY COURSE: *A Multicriteria Comparative Study*

Mr. TRY Sokkeang

Master degree in Construction Management, Sirindhorn International Institute of Technology, Thailand

Ms. HEANG Ngech Horng

Master Degree in Environmental Engineering, Kasetsart University, Thailand

Executive summary

The emergence of the COVID-19 outbreak triggered great changes and caused rapid adoption of virtual learning approaches using advanced technologies. Compared to physical learning at school, virtual learning approaches still have significant limitations, especially for courses that require interactive experiments. The study was conducted by exploiting the benefits of VR technology to deal with the above issue and to achieve the following objectives (1) to develop a VR application to support a laboratory course in Civil Engineering education and (2) to measure the potential VR application compare with actual learning with the instructor and video-based learning approach. The experiment was done with 26 Civil Engineering students, and the result obtained from the experiment was analyzed using Analytic Hierarchy Process (AHP). The results depicted that VR application is better than the Video-based learning approach in terms of the following aspects, including "interactivity" (the ability to provide both theoretical learning and active practice simultaneously), "cognitive interest" (the ability to trigger users' interest to study), "ease of understanding the content" (the ability to generate a clear explanation of learning

content), and "support for learning" (the ability of the application to support learning activity and help learners to reach their learning objectives). Although the VR-based approach was found less favorable than the Actual Instructor-based approach, it was proved to be more effective in capturing learners' interest. It could provide better access to education where learning could be done at any time and place as preferred by the learners.

Keywords: *Virtual Reality, Head Mounted Devices (HMDs), and Analytic Hierarchy Process (AHP)*

1. Introduction

Farshid et al. (2018) introduced the term "Reality Continuum" which consists of the following:

- **Reality**: real objects/environment that could be physically interacted with.
- **Augmented Reality (AR)**: allocation of digital information and/or virtual objects into an actual world.
- **Virtual Reality (VR)**: refers to three-dimensional (3D) graphics representing real-world/objects.
- **Mixed Reality (MR):** integrating both virtual and actual environments. A Mixed Reality environment can be both actual and virtual.
- **Augmented Virtuality:** the allocation of real objects into a virtual environment.
- **Virtuality:** refers to virtual objects/ environments that can exist in the real world.

A definition of VR refers to two-dimensional (2D) and/or three-dimensional (3D) graphics representing a real environment or imaginary world produced by computer systems (Sherman & Craig, 2003). It is an experience that users could visualize and immerse partially or fully into a virtual environment using add-on instruments such as headsets. The first VR equipment was invented in 1962 by Morton Heilig, a cinematographer (Carmigniani et al., 2011; Mazuryk & Gervautz, 1996). Over decades, plenty of VR tools has been created, such as Google VR Cardboard, Google Glass, Oculus Head-mounted devices (HMDs), HTC VIVE HMDs, plus many others.

VR has four main features stated by Sherman and Craig (2003) including 1). Virtual world: computer 3D graphics of a real-world or imaginary environment, 2). Immersion: a process of immersing or simulating oneself into a nonphysical or virtual world, 3). Sensory Feedback: movement and orientation of objects detected by computer systems, and 4). Interactivity: manipulation and interaction between users and virtual world/ objects.

To date, VR technology has become one of the trending topics in the research field. Various studies on VR technology were found, including "Virtual Museum (VM)", which allows visitors to visualize and navigate through a 3D environment (Barbieri et al., 2017), and "Surgical Simulation", which is more cost-effective than the real training room as well as allows users to conduct training that can be repeated and avoid potential risks (Haluck & Krummel, 2000). Existing studies indicate that the integration of VR technology into the educational curricula could improve teaching effectiveness (Tarng et al., 2019). VR use cases are also found in the civil engineering field. VR high immersive usage could boost students' knowledge to another level (Messner & Horman, 2003).

2. Methodology

The VR application was built, as shown in Figure 1, using Unity Engine Software and constructed specifically for HTC VIVE HMDs. First, the 3D models were built using Autodesk AutoCAD 3D, Sketch Up, and Blender software and then exported to Unity Engine as an FBX file extension. C-Sharp program language was used for coding the VR functionalities, including animation, interaction, and other VR functionalities. Finally, the application was exported as an APK file for testing. The scenarios within the VR application were built based on pedagogical aspects adopted from (Zhou et al., 2018) including (1) learning objectives, (2) learning style, (3) learning activities and tasks, and (4) constructing a motivated learning prototype.

The VR application was built, as shown in Figure 1, using Unity Engine Software and constructed specifically for HTC VIVE HMDs. First, the 3D models were built using Autodesk AutoCAD 3D, Sketch Up, and Blender software and then exported to Unity Engine as an FBX file extension. C-Sharp program language was used for coding the VR functionalities, including animation, interaction, and other VR functionalities. Finally, the application was exported as an APK file for testing. The scenarios within the VR application were built based on pedagogical aspects adopted from (Zhou et al., 2018) including (1) learning objectives, (2) learning style, (3) learning activities and tasks, and

(4) constructing a motivated learning prototype.
The experiment was conducted with 26 university students between 19 to 30 years old. Since the study aimed to measure only learners' perspectives, professional levels, including teachers and experts, were excluded from the study. Only civil engineering students were eligible for the experiment. Participants were asked to conduct learning randomly using three approaches, including Video-based (conduct learning through watching a 2D video), Actual Instructor-based (conduct actual learning with support from an instructor), and VR-based (conduct learning using VR application) approaches.
Preceding the experiment, each participant was asked to fill out the assessment form to measure their preferences over the three approaches. The study used Analytic Hierarchy Process (AHP) for assessment and analysis. The evaluation and comparison of the three learning approaches were based on five criteria include interactivity (learning approach could provide both theoretical learning and active practice simultaneously), accessibility (learning approach is accessible at any time and place based on learner preference), cognitive interest (learning approach can trigger users' interest to study), ease of understanding the contents (learning approach could provide a clear guideline and explanation to the learners), and learning support (learning approach could support learning activity and help learners to reach their learning objectives). AHP is a pairwise comparison method in which absolute scale factors from 1 (equally important) to 9 (extremely important) were used. The study also involves an interview to measure the participants' perspectives on the VR-based approach as well.

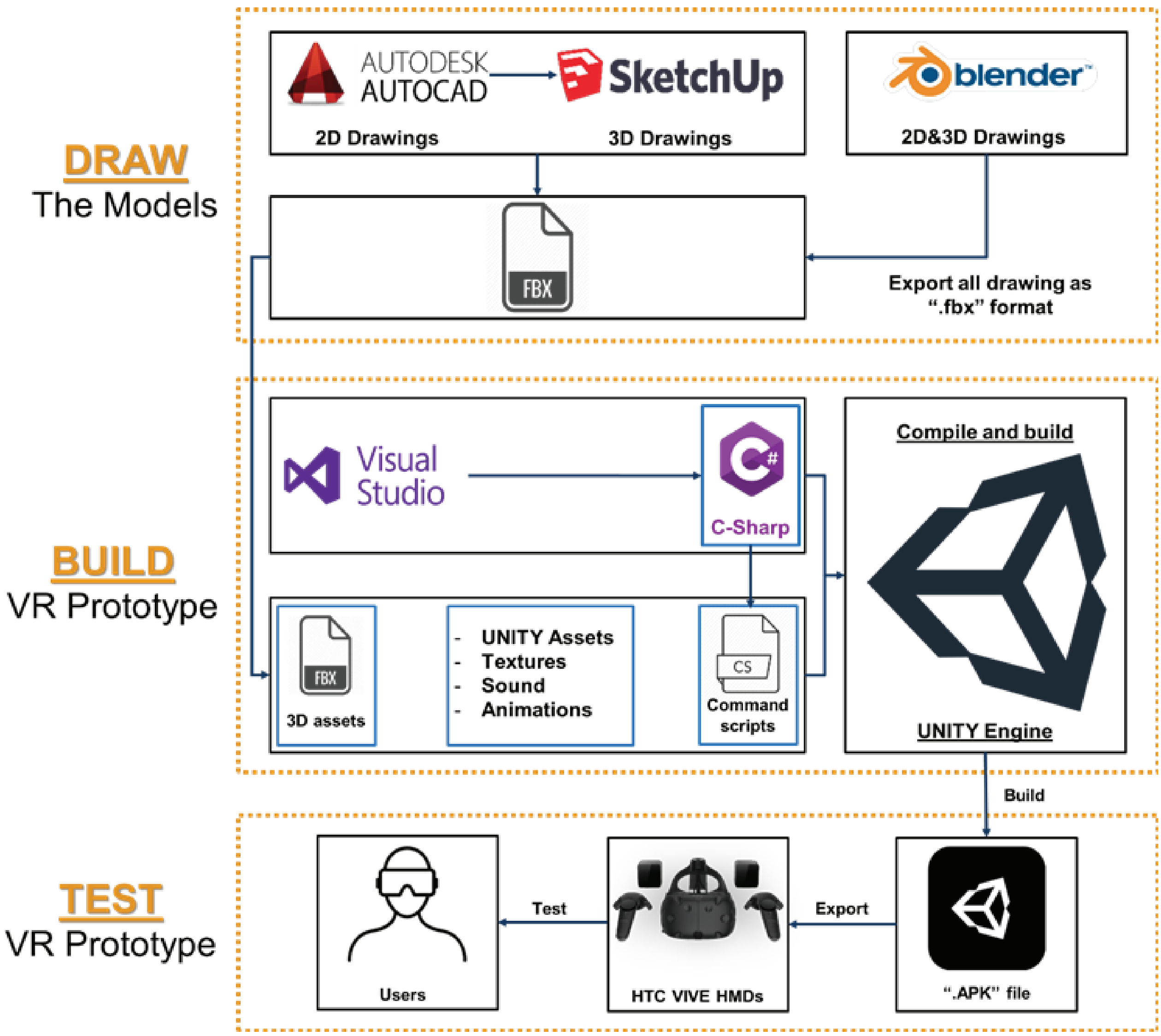

Figure 1. System architect.

3. Findings

The overall result from comparing the three learning approaches indicates that learners still prefer the most actual instructor-based learning approach, as shown in Figure 2. VR approach was ranked from participants' perspectives as the second most preferred approach, while the Video-based learning approach is ranked as the least preferable. By considering the criteria used for the evaluation VR-based approach was regarded as better than the Video-based approach in terms of the following criteria, including interactivity, cognitive interest, ease of understanding of the contents, and learning support. Although the VR-based approach was overall less preferred by participants compared to the actual instructor-based approach, the VR-based approach was regarded as more potential in terms of "accessibility" and "cognitive interest" criteria. In addition to the AHP assessment and analysis technique, a short interview was done with each participant. The result indicates that participants have a positive impression of the VR-based approach. Participants described the VR-based approach as interesting and engaging, which could reduce educational pressure and caus no property damage while generating a realistic 3D environment.

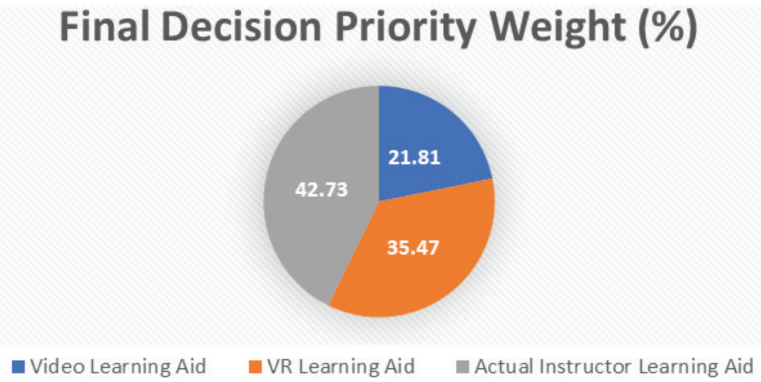

Figure 2. Final priority weight of the three learning approaches.

4. Conclusion

In conclusion, the study emphasized partially two items within the civil engineering laboratory, including "non-destructive hammer" and "resistivity meter". The study shows that VR application does have significant advantages over the video-based learning approach. On top of that, the VR-based learning approach also has the upper hand over the Actual Instructor-based Learning approach in terms of "Cognitive Interest" and "Accessibility". Despite being ranked as the second most preferable learning approach and receiving a positive impression from participants, the VR-based approach still contains many limitations. First, the interaction built within the virtual environment does not fully anticipate real interactions. Second, the interaction between users and 3D objects is hard to control, and the instrument (HTC VIVE HMDs) is bulky. Most importantly, this study measured only the preferences of users while other factors, including the effectiveness of the VR-based approach, were not measured. On top of that, the application was built as an offline and single-user application which limits the users from studying as a team.

Some recommendations for future study include (1) developing a multi-users online VR-based learning application to support learning and (2) Developing a fully equipped functionalities VR application for hands-on learning activities.

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STI POLICY

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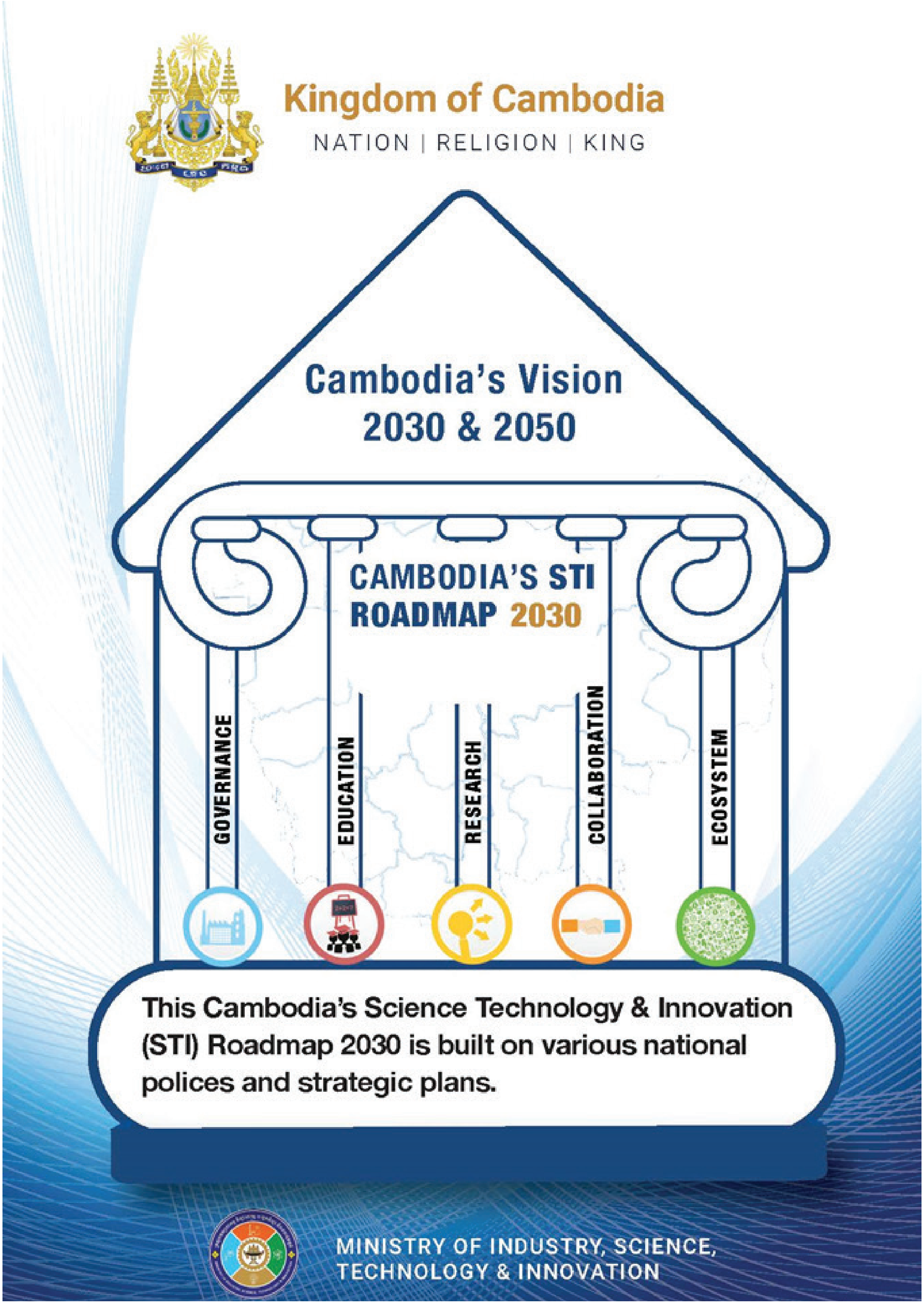

06 CAMBODIA'S SCIENCE TECHNOLOGY AND INNVATION ROADMAP 2030

Dr. SRUN Pagnarith
PhD in Engineering, University of Tokyo, Japan

Executive summary

- The Royal Government of Cambodia (RGC) is determined to become an upper middle-income country by 2030 and a high-income country by 2050 in her Vision 2050.
- Science, Technology and Innovation (STI) will be the driving force and locomotive to realize Vision 2050 and achieve sustainable and inclusive development goals.
- Understand the importance of STI, RGC has rolled out National Science, Technology & Innovation Policy 2030 in 2019.
- Ministry of Industry, Science, Technology and Innovation (MISTI) has established in 2020 to serve as the main coordinating body and oversee STI in Cambodia under the guidance of the National Council of Science, Technology & Innovation (NCSTI), which was established shortly after.
- Cambodia's Science, Technology & Innovation Roadmap 2030 has been developed to help implement National STI policy and to harness the power of Science Technology and Innovation as a locomotive and driving force for sustainable and inclusive economic development to achieve RGC's vision 2050, mainly targeted 5 pillars include 1) Governance, 2) Education, 3) Research, 4) Collaboration, and 5) Ecosystem.

Keywords: *Roadmap, Science, Technology and Innovation (STI), National Innovation System (NIS), Socio-Economic Development, Sustainable and Inclusive Development, Royal Government of Cambodia (RGC)*

The Royal Government of Cambodia (RGC) has set out an ambitious vision to become an upper middle-income country by 2030 and a high-income country by 2050. To realize this vision, strengthening national technological capabilities and improving innovation performance will be critical for this realization and also addressing the urgent developmental and societal challenges. Science, technology and innovation (STI) will be a pivotal driver in shifting the economic development pathway from a focus on traditional growth to support for inclusive and sustainable growth. STI will enable and accelerate the structural transformations required to increase national prosperity, peace, security, safety, and socio-economic development and to improve quality of life. The transfer and, when necessary, an adaptation of technologies from developed countries can often contribute significantly to these goals. Substantial research efforts are needed to find solutions that address other global challenges. Effective international cooperation that involves both public and private bodies is an important mechanism for finding these much-needed solutions.

Moreover, one of the important lessons of the past two decades has been the pivotal role of innovation in economic development. The build-up of innovation capacities has played a central role in the growth dynamics of successful developing countries. These countries have recognized that innovation is not just about high-technology products and that innovation capacity has to be built early in the development process so that learning can enable "catch up" to happen. They also need innovation capacity to address local challenges (e.g., pandemics) through innovation. Ultimately a successful development strategy must build extensive innovation capacities to foster economic growth.

Aware of the challenge ahead, the Prime Minister of the Royal Government of Cambodia approved the **National Science, Technology & Innovation (STI) Policy 2020–2030** in December 2019. The main objectives of the National STI Policy are strengthening the STI foundation (human resources in science and technology, research and development (R&D), institutions), improving the STI ecosystem (framework conditions, relevant laws, and regulation, synergy across organizations) to support an innovation environment for sustainable and inclusive development, and developing an STI environment for sustainable development and enhance the quality of people's lives at all levels and in all sectors. The National STI Policy of Cambodia aims to harness the power of STI as a driving force for inclusive and sustainable socio-economic development to achieve the country's Vision 2050 of becoming an upper-middle income country by 2030 and a high-income economy by 2050 and achieving national goals for sustainable development. The National STI Policy seeks to achieve these objectives by adopting and adapting technologies and promoting further innovation. Most recently, the RGC has decided to establish two new institutions to oversee the STI development in Cambodia, namely the Ministry of Industry Science Technology & Innovation (MISTI) to serve as a main coordinating body for STI policies among key ministries, and the National Council of Science Technology and Innovation (NCSTI) as a national body to set the direction of STI policy in Cambodia.

Shortly after the establishment of these two institutions, the RGC has developed and adopted strategic Cambodia's Science Technology and Innovation Roadmap 2030 to harness the power of Science Technology and Innovation as a locomotive and driving force for sustainable and inclusive economic development to achieve RGC's vision of 2050. This STI Roadmap 2030 was developed based on an assessment of Cambodia's National Innovation System and consultations held with stakeholders across different ministries, academia, and the private sector (interviews, and workshops). It has also been taken into account the strengths and weaknesses of the National Innovation System (NIS) in Cambodia and targets five main pillars, namely: **1) Governance, 2) Education, 3) Research, 4) Collaboration,** and, last but not mean least, **5) Ecosystem.**

This Cambodia's STI Roadmap 2030 was designed to guide the implementation of the National STI Policy 2020-2030. This Roadmap is summarized in figure 1 and described below.

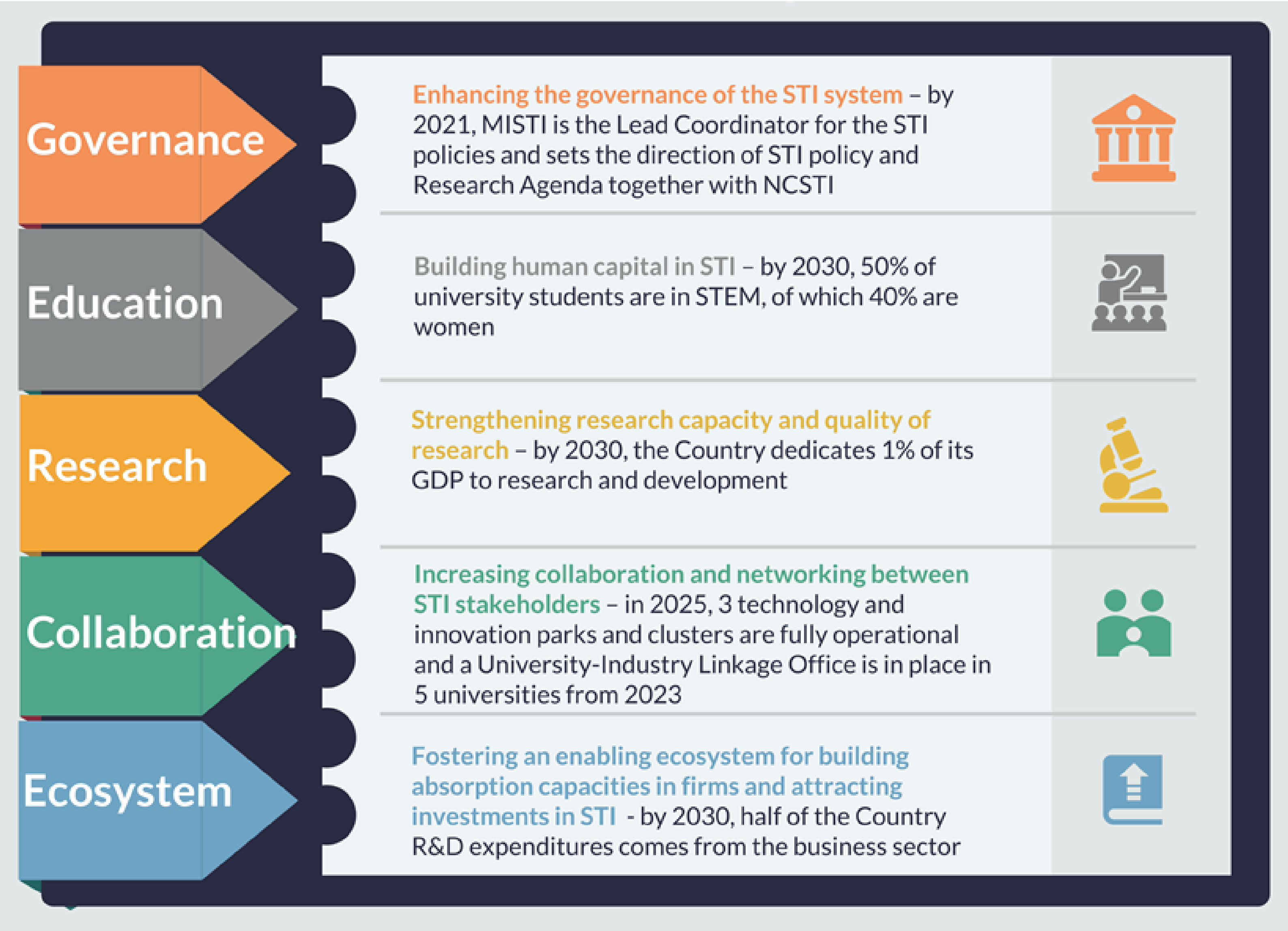

Figure 1. STI Roadmap 2030.

- **Enhancing the governance of the STI system**: STI governance is key and has been recently restructured with the creation of MISTI in March 2020. It will be important to consolidate this new structure while reducing fragmentation and breaking down silos. This will require clarifying the role of MISTI and other stakeholders, strengthening the awareness and capacities of the Government to implement the National STI Policy, and monitoring and evaluating advances made in the promotion of STI.
- **Build human capital in STI:** Current demand for innovation is low and there is a limited scientific and entrepreneurship culture. It will be critical to promote scientific, digital, and entrepreneurship literacy, and the technological readiness of the youth, starting with basic education. Teaching science, technology and innovation from a very early age will help create a new generation of scientists and innovators. Skills in science technology engineering and mathematics (STEM) will also need to be promoted in higher education. In addition, there is room for strengthening teaching and collaboration with the private sector in technical and vocational education and training (TVET) institutions. Strategic development of human resources is at the foundation of promoting STI.
- **Strengthening research capacity and quality**: Building the capacity of the higher education and research system to conduct high-quality R&D activities of national interest and in priority sectors are much needed. This will require developing a national research agenda with the academic community and in close collaboration with the private sector, providing funding to support excellent science and the internationalization of research and encouraging collaboration with the private sector.
- **Increasing collaboration and networking between different actors**: Innovation comes from the exchange of ideas, across different people, organizations, sectors, and scientific domains. Intermediary organizations and knowledge broker institutions are essential to facilitate such exchanges. Hence, it will be critical to promote and sustain incubation and acceleration facilities, technological platforms open to the private sector, and innovative clusters fostering collaboration to support innovation in small and medium-sized enterprises (SMEs) and enhance their absorptive capacities.
- **Fostering an enabling ecosystem for building absorptive capacities in firms and attracting investments in STI**: Supporting innovation capabilities and increasing the absorptive capacities of firms requires financing and promoting intermediary structures that nurture new firms (start-ups), support technology transfer, and promote domestic technologies. It needs to be fostered by institutions that provide technology and quality (norms and certification) services to firms. It also requires increasing access to finance for innovation activities, including leveraging investments from the private sector and attracting funding from donors. Incentivizing foreign direct investment (FDI) that supports the building of domestic technological capabilities, facilitating the importing of technology equipment, and promoting intellectual property rights are additional avenues for fostering an enabling ecosystem for innovation.

The implementation of these priorities will rely on a partnership between the public sector, including relevant ministries, government agencies, universities, research institutions, development partners, civil society, and the private sector. Firms, from start-ups to SMEs to large foreign corporations, and business associations, play a key role in STI, being the most prominent innovators, investors, and users of technologies. The Government cannot instruct the private sector to invest in STI activities, but it can certainly encourage investment through regulations, and incentives, enabling an innovation-friendly environment, and building the relevant infrastructure. Furthermore, it will be vital to consult and engage multiple international development partners that can further support the implementation of the proposed actions through technical and financial assistance.

07 MONITORING AND EVALUATION ON CAMBODIA'S SCIENCE, TECHNOLOGY AND INNOVATION 2030

Dr. CHEAT Sophal
PhD in pathology, toxicology, genetic, and nutrition, University of Toulouse III, France

Mr. SOUER Chumnith
Master degree in Educational Management and Planning, Kyoto University, Japan

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Executive summary

Monitoring and evaluation (M&E) are the keys to the efficiency and effectiveness, and success of Cambodia's Science, Technology and Innovation (STI) roadmap 2030 implementation. Therefore, through desk review, multiple technical meetings, and consultation workshops, a fine-tuned result framework with 31 indicators, their definitions or descriptions, baseline values, targets, and key stakeholders were completely developed. To accomplish this framework, robust M&E system building, data analysis, professional report writing, and annual work plan are critical for M&E this roadmap and future STI policies.

Keywords: *M&E system, Indicators, Framework*

1. Problem statement, objective

Monitoring is a continuous process that collects data on specific indicators to assist decision-makers at the levels of inputs, actions, and outputs to gain an overall picture of performance (Marriott & Goyder, 2009). After seeing monitoring results that are not as planned owing to implementation challenges and changes in the context, it allows decision-makers to decide whether to continue, drop, or alter activities (IDEA, 2021). An evaluation is a rigorous and objective assessment of ongoing policy, project, or program operations (Marriott & Goyder, 2009). Examine and clarify the relationship between outcomes achieved and policy, program, or project objectives, as well as its contribution to overall goals, efficiency, effectiveness, impact, and sustainability (IDEA, 2021). There must be a monitoring and evaluation (M&E) department/office/unit with particular tasks and functions to plan and implement operations, monitor, consolidate, harmonize, and improve data quality and information flow.

The Governance, Education, Research, Collaboration, and the Ecosystem are the five pillars of Cambodia's STI Roadmap 2030, signed on July 26th, 2021. To make this roadmap a success, the Department of Monitoring, Inspection, and Evaluation (D/MIE) needs to work closely and collaboratively with all key stakeholders, ministries, and entities to collect and analyze data and then report results as required (MISTI, 2020). Cambodia's STI Roadmap 2030 requires that the Ministry of Industry, Science, Technology and Innovation (MISTI-D/MIE) develop a M&E system to track key policy targets as well as indicators, inputs, and activities. A partnership with the Ministry of Planning (National Institute of Statistics) will be created to provide more data and statistics on governmental and private sector innovation performance. This includes 1) conducting an enterprise innovation survey every three or four years and utilizing international standard computation methodology, and 2) assessing the effectiveness of this Roadmap and making adjustments as needed every three or four years.

To achieve these goals, a comprehensive system of tracking and evaluating all proposed policy documents is required. MOWRAM (2012) defined M&E as a management tool used to track the achievement of set targets, information gathering, and synthesis, reflection, and reporting processes, as well as the necessary supporting conditions for M&E outputs to make a valuable contribution to program or project decision making, learning, and policy dialogue (IDEA, 2021). Technical components (monitoring and evaluation) and institutional components (organizational structure, stakeholder participation, capacity building, and advocacy for M&E) are the fundamental components of the M&E system.

2. Methodologies and the importance and application of study

In 2021, D/MIE achieved designing a fine-tuned result framework that contains 31 indicators, their definitions or descriptions, baseline values, targets, and key stakeholders through desk review, numerous technical meetings, and consultation workshops. It is the first step in keeping track of and evaluating Cambodia's STI Roadmap 2030. This M&E framework has been designed to collect data from important stakeholders regularly through the monitoring and reporting mechanism. Regular progress reports from all linked stakeholders are sent out on a biennial, and annual basis to MISTI. The reports will be compiled by D/MIE and sent to the secretary of the National Committee on Science, Technology, and Innovation (NCSTI), which will then submit to the NCSTI for review. It will be necessary to record and collect data through the M&E system, which is scheduled to go into effect in 2022. Finally, the final draft of the M&E guideline has been produced by D/MIE to ensure the smooth operation of the M&E system and the timely delivery of results to decision-makers and senior management. To support the M&E guideline, manual, framework development as well as STI policy implementation monitoring and evaluation, D/MIE organized a series of five workshops on M&E system development visioning to a digital platform. These actions were taken to disseminate knowledge about M&E and build capacity among all levels of MISTI staff.

There will be no improvement in the General Department of STI's M&E culture unless a precise annual work plan or annual work plan budget is produced and implemented efficiently with the support of the M&E System. Even if a precise M&E system is in place with properly defined operational and organizational procedures, new and inexperienced staff contribute to the system's delayed performance. The system will collapse or not work if everyone fails to carry out their duties.

3. Challenges and future perspective

The following measures should be taken to meet the aforementioned challenges and changes: 1) timely recruitment of some new and qualified staff with relevant fields to D/MIE; 2) prioritization of capacity building for D/MIE technical staff, namely system building, data analysis, and professional report writing; 3) recruitment of a technical assistant on M&E to assist in system building and capacity building for the department; and 4) the quality of M&E results must be ensured and used to guide policy development, especially supported decision-making in the organization. Despite the small number of staff and limited experience, the D/MIE staff has attempted learning through experience, taking responsibility for all accomplishments. It is the ideal opportunity for MISTI to place M&E in a developmental stage, and for M&E professionals to develop their competence via doing and learning.

To effectively implement Cambodia's STI Roadmap 2030, D/MIE commits to and prioritizes the following programs:

- Develop a M&E system for Cambodia's STI Roadmap 2030
- Create the STI M&E Guideline and digital platform
- On-job training for employees in the fundamentals and advance of M&E (series of training)
- Construct M&E framework, plan, and system to ensure STI policy implementation efficiency and effectiveness
- Organize frequent management (technical) meetings to review Cambodia's STI roadmap 2030 execution and report writing workshops
- Report on Cambodia's STI roadmap 2030 implementation to MISTI and NCSTI every six months.

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08 | INNOVATION, INVENTION, AND INTELLECTUAL PROPERTY

Ms. ING Chandavya
LL.M. Intellectual Property and Competition Law, Munich Intellectual Property Law Center, Germany

Executive summary

We all know that we need something new to improve what we currently have and to make our lives easier. The term "Innovation" might be fancy enough to capture the attention of researchers and developers so that they could be innovators. However, there is not always a smooth path to success. Although pride could keep a researcher or developer motivated in pursuing their goal, failures always come in between, and it takes lots of investments to reach the goal, causing lots of them to give up. That is why intellectual property comes into play to ensure that those researchers and developers are not investing in anything since the result of their research and development could somehow become their intangible property, and they would be able to benefit from such property by being able to control over how their property is used.

When talking about innovation, the invention would come into mind as it is the bedrock of innovation. In Cambodia, inventions are governed under the Law of Patents, Utility Model Certificates, and Acts of Unfair Competition. The main responsible authority is the Ministry of Industry, Science, Technology & Innovation.

1. Innovation, invention, and intellectual property

In the era of digitalization, research and development in science and technology have always been supported and encouraged. One would not have envisioned that we could talk to a business partner living in another part of the world, as if we were in the same room, via a flat-screen device. With the upcoming virtual universe like the Metaverse by Meta, Inc., we are expecting more innovations, and these could not happen without research and development. However, what are the incentives to do so?

2. The Link Between Innovation and Intellectual Property

The World Intellectual Property Organization ("WIPO") provides a general definition of the term "Innovation" as "doing something new that improves a product, process, or service" and at the same time, defines the term "Invention" as "a new solution to a technical problem". Inventions are said to be the bedrock of innovation (WIPO, 2017). Although both terms are about the new idea, the concern of innovation is the commercialization of new ideas while invention does not necessarily need to be directly associated with commercialization (Mark Rogers, 1998). Since not all inventions are commercialized, it is evident that not all inventions lead to innovation. Many new ideas are born, but "most die a lonely death, never seeing the light of commercial success" (Brandt, J.L., 2002).

It would take a lot of investment for a person to persist in researching or developing something new. Innovators need fair returns on their investment in creative activities to do more research and development that would lead to innovation (UNIDO, 2006), which is the job of intellectual property. The same applies to inventors in terms of inventions. Intellectual property would allow the innovators, inventors, or owners to benefit from their work by giving them control over how their work is used (WIPO, 2020). That indicates a link between innovation, invention, and intellectual property.

When talking about intellectual property, the terms "Innovation" and "Invention" were not completely differentiated. While different types of intellectual property, patents, utility models, and trade secrets are equally important for protecting, managing, exploiting, and leveraging innovation, just as they are for invention (WIPO, 2005). However, just as defined above, the term "invention" could describe the new idea, at any stage, including when determining whether it could qualify for intellectual property protection. In contrast, the term "innovation" is used to describe such things once it has commercial value.

3. Protecting your Invention in Cambodia

In Cambodia, the protection of an invention is governed under the Law on Patent, Utility Model Certificate, and Industrial Design ("Patent Law"), which one of its objective is "to encourage innovation". Under the Patent Law, the term "Invention" has been defined as "an idea of an inventor which permits in practice the solution to a specific problem in the field of technology" and it could be a product or a process. The main responsible authority is the Ministry of Industry, Science, Technology & Innovation.

3.1. Patent

A patent is a title granted to protect an invention. An invention is patentable if it meets three criteria; (i) new, (ii) involves an inventive step, and (iii) industrially applicable (Patent Law, 2003). However, according to Article 4 of the Patent Law, certain inventions do not qualify for patent protection. These include the following inventions:

- Discoveries, scientific theories, and mathematical methods;
- Schemes, rules, or methods for doing business, performing purely mental acts, or playing games;
- Methods for treatment of the human or animal body by surgery or therapy, as well as diagnostic methods practiced on the human or animal body;
- Pharmaceutical products;
- Plants and animals other than micro-organisms, and essentially biological processes for the production of plants or animals;
- Plants varieties.

For pharmaceutical products, Cambodia was granted an extension under the TRIPs Agreement not to oblige to provide patent protection due to its status as a "least-developed country". This extension is set to be applicable until January 1st, 2033, or the day when Cambodia ceases to be a least developed country member, whichever date is earlier (Law on Amendment, 2017; see also, Decision of the Council, 2015).

Patent protection will expire 20 years from the filing date of the application, and the owner also needs to pay an annual fee to maintain the patent protection until such an expiration date. The owner of the patent would have an exclusive right over the exploitation of the patent in a way that any other person cannot exploit the patent without the agreement of the owner. If a patent is granted in respect of a product, exploitation would include the making, importing, offering for sale, selling, and using of a product as well as the stocking for offering for sale, selling, or using of such products. If a patent is granted in respect of a process, exploitation would include the using of the process, and the making, importing, offering for sale, selling, using, and stocking for offering for sale, selling, or using of a product obtained directly through the process (Patent Law, 2003).

3.2. Utility model certificate

A utility model certificate is a protection granted for a utility model. An invention that is new and industrially applicable could be protected under a utility model certificate. Certain inventions that do not qualify for patent protection, as mentioned in Section 3.1 above, would also not qualify for protection under a utility model certificate. A utility model certificate would expire, without any possibility of renewal, after seven years from the filing date of the application. The owner of the utility model certificate would have an exclusive right over the exploitation of the utility model, and the exploitation is interpreted in the same way as for patent (Patent Law, 2003).

A utility model certificate is different from a patent in a way that it does not require the invention to involve an inventive step. Generally, utility models are primarily used for mechanical innovations that make minor improvements, and adaptations to, existing products. In some countries, it is referred to as "petty patent". Therefore, an invention that failed to involve an inventive step might qualify for protection under a utility model certificate.

Researchers and developers should take advantage of this intellectual property protection so that their hard work is paid off.

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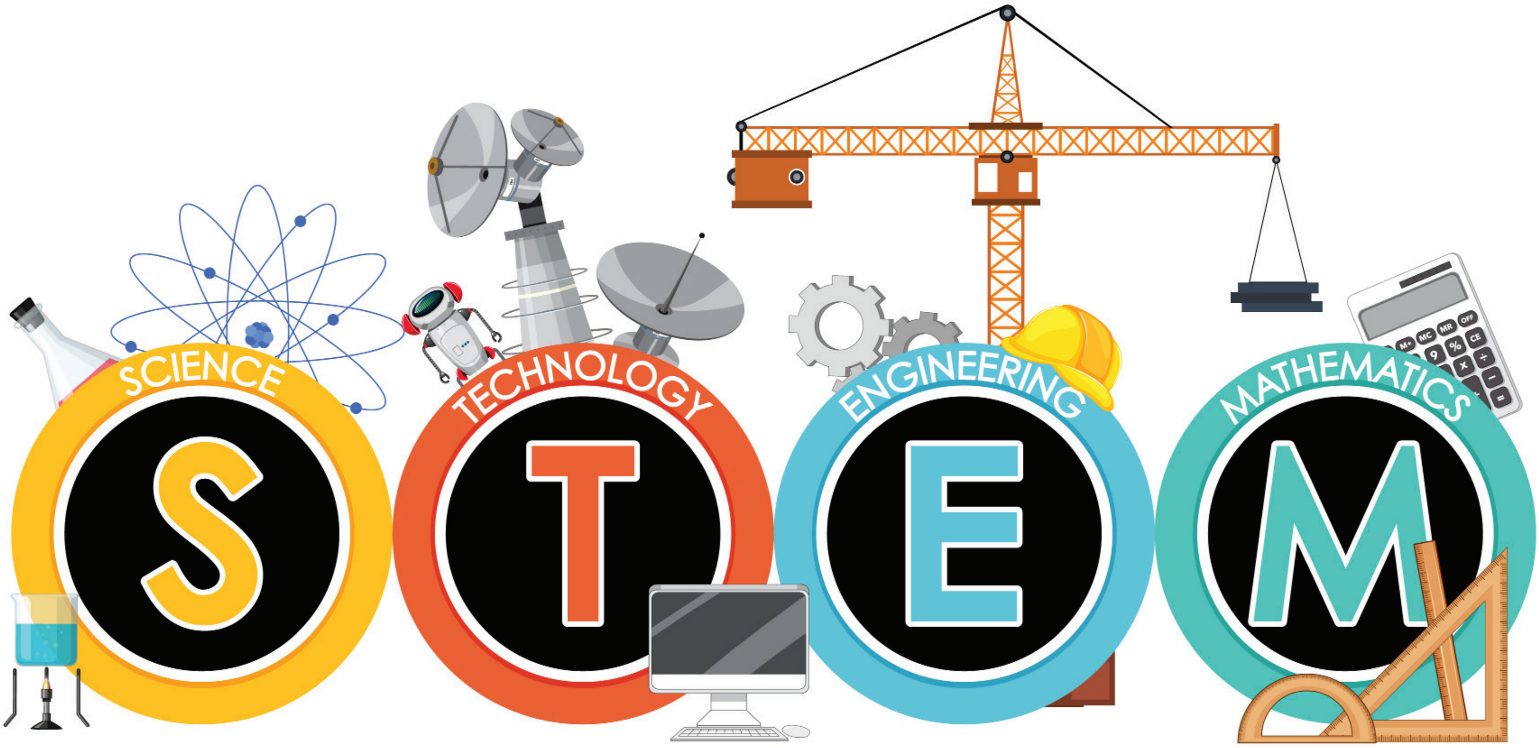

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Education and Careers

09 ECONOMICS OF SCIENCE, TECHNOLOGY AND INNOVATION

Dr. CHEA Vatana
PhD in Demography, Chulalongkorn University, Thailand

Ms. ING Sopheap
Bachelor degree in International Economics from the Institute of Foreign Languages (IFL), Royal University of Phnom Penh (RUPP), Cambodia

Executive summary

- Rapid development across the globe that we are witnessing today cannot be explained without taking advancements in science, technology and innovation (STI) into account. But it also begs the question of whether STI cause economic growth or the other way round.
- Despite acknowledging technology as a contributor to economic growth, the Solow growth model views it as being determined outside the economic system and beyond the influence of economic instruments. On the other hand, Endogenous Growth Theory believes that economic policies can be used to control or stimulate technological progress.
- To drive technology and innovation, a dilemma between publicizing new knowledge or ideas and promoting scientific research also arises. Making knowledge cost-free for the public will take away firms' and industries' incentives to invest in R&D while allowing firms and industries to have exclusive control over certain technologies or knowledge will prevent the public from accessing the knowledge and further contributing to building on the discoveries.
- Innovation is not only about creating brand new products, but also entails the improvement in certain aspects of a company or industry, such as marketing or organizational methods. Hence, it is inarguably within the capacity of

firms and industries in a developing country like Cambodia.

- The government should also invest in scientific research alongside the private sectors because it is not ideal to have only firms control over the market of technology and R&D, as they can increase and exploit their market power. Consequently, the development of STI driven by firms might occur at the expense of the mass, and that scientific research is no longer done to maximize public welfare.

Keywords: *Science, Technology, Innovation, Economic Growth*

1. Background

For a long history of the human race, as far as one can remember, the world has never experienced such rapid development as one has seen since the second half of the 20th century. Gross Domestic Product (GDP) per capita has increased by tens of thousands of dollars, and life expectancy at birth in what is now developed countries rose from approximately 65 to more than 80 years old between the 1950s and 2010s. Men have never been more prosperous than we are now, but what drives the economic growth, and if that matters, the growth of overall welfare? Is it due to the improvement in modern technologies? This paper conducts a desk review and aims to provide essential elaboration on the relationship between scientific advancement and economic growth and the important role of economic thinking in the development of science, technology, and innovation. We would argue that one cannot fully understand how science and technology progress and promote science in the interest of the mass without a fundamental understanding of economics and how the economic system works. While it is generally correct to say that scientific and technological development leads to more economic growth, the opposite is also true. And that is our motivation for writing this short article – to explain why it is so.

2. Science, Technology, and Economic Growth

STI pique economists' curiosity because technological changes and innovation are the engines of long-term economic growth, and scientific advancement is the engine of technological changes and innovation. This is particularly true considering one fact that the advances in computers and the internet have contributed substantially to the improvement in the services sector and that most of us do not need a travel agent to book air tickets and hotels anymore. In addition, we can buy groceries and have them delivered to our doorstep using just a mobile phone. But at the national level, the economic system is more complicated than that. In an attempt to explain the phenomenon, economists have been trying to develop various theories, the nature of which ranges from simple to sophisticated. However, one of the most fundamental and powerful growth theories is the Solow Growth Model (Solow, 1956), named after a Nobel laureate in economics – Robert Solow, who helped us better understand the dynamics and causes of economic growth. Solow's simplified framework consists of three important factors of production leading to exponential improvement in productivity and expansion of utilities namely labor, capital, and technology or ideas/knowledge.

But while Solow did talk about technology, his discussion largely focused on saving and investment or capital accumulation, and he assumed that technology grows exogenously even though he acknowledged that countries need technological development to accelerate productivity and sustain the economy in the long term. In other words, he believes technological progression is independent of economic growth and outside the influence of economic forces, and thereby cannot be managed by any economic framework. Such assumption was challenged by the Endogenous/New Growth Theory (Romer, 1994). One of the most prominent individuals who have largely contributed to the development of such theory is Paul Romer, another Nobel laureate in economics. Romer asserted that the rate of technological progress can be controlled by internal factors within the economic system and can thus be influenced by economic policies. To support his claim, he indicates that new products and methods of production, which are the representation of the discovery of new ideas and technological improvement, are mainly produced by economic activities. For example, the development of many features in a smartphone including touchscreen, Touch ID, Face Recognition ID, etc. are funded by leading private companies in the business, such as Apple and Samsung, whose sole purpose is to attract global customers and make money rather than just purely about scientific evolvement. As a result, it is perhaps of little surprise to learn that 71 percent of Research and Development (R&D) funding in the United States in 2019 comes from industries whereas the federal government only contributed about 21 percent of the total amount (Boroush, 2021).

For now, it might be less debatable that economic growth also causes improvement in science and technology, and that investment in technological development can also be driven or contributed by firms or industries who, to a great extent, benefit from both the growth of national and individual income. But firm-driven R&D or any knowledge generated by firm-funded research does not have properties of a public good at least for a certain period because once it is discovered, a firm will patent their invention to exclude the general public or other companies from using it. Nevertheless, we are not saying that such practice is completely detrimental because if knowledge is made freely accessible for everyone, no one will be willing to pay to invent new knowledge as they can free-ride. Therefore, making scientific knowledge free for all will kill the scientific progression and new technological discoveries, for the inventor will benefit nothing from it, and therefore they have no incentive to do so. However, we will not be able to make the best use of new knowledge or ideas either if the general public is excluded from using them. Why? Because knowledge or ideas are non-rivalrous. Unlike natural resources, knowledge is not depleted when we use or share them. On the contrary, knowledge is often enlarged once it is made public because many other people can also develop on them and make them even better. And the incremental cost of an additional user is almost zero (Stephan, 1996). For example, while it takes a company millions of dollars to invent the vaccines for COVID-19, it takes only a few dollars or less to produce them once we have the knowledge of chemical formulas and how to produce them. In addition, the vaccines can also be imitated and produced by other pharmaceutical companies at virtually no cost if the inventor is willing to share the knowledge. However, it is not practical in reality, which is why many developing countries still have limited access to COVID-19 vaccines.

This is a dilemma of publicization of knowledge or promotion of scientific research, and economists have been concerned over the fact that a competitive market does not efficiently provide sufficient incentives for the production of public goods such as new public knowledge. Simply put, economists think that the competitive market has not succeeded in maximizing societal utilities even though there has been a remarkable improvement in science and technology, and we are experiencing

a form of market failure. But that is the situation in which individuals and the government can play a role in correcting the market system and making new knowledge a public good by investing in education, scientific research, R&D, innovation, etc. which in turn become a source of growth leading to higher saving and investment in technology, a feedback loop. Such investment decision is also a major factor in moving a country away from a labor-intensive base and breaking it free from the middle-income trap. Therefore, we would maintain that the development of technology, R&D, and scientific research should not depend mainly on financial support from the industries but also on the government due to obvious reasons. Even though knowledge is expensive to generate because it requires not only resources but also time and cognitive input, and sometimes even serendipity. Some economists believe that knowledge or ideas, like capital, also face diminishing returns meaning that it continues to require more people and resources to generate the same amount of knowledge now than it did before.

It is in this sense that we think research cannot simply exist without highly-educated people. However, it is not entirely true to assume that innovation is also only within the capacity of an intellectual and educated workforce from the centers of excellence in the world of science and is usually conducted in companies with an intensive focus on R&D. Innovation is often wrongly perceived to be associated with the use of the state-of-the-art knowledge to create brand new and advanced solutions to fulfill the demands of sophisticated and affluent people. In this regard, innovation is only considered to be the developed world's activity while being of little to no relevance to the developing world (Fagerberg et al., 2010). However, innovation can be defined in a broader sense simply as a new marketing or organizational method in business practices, workplace, and external relations. Therefore, innovation is not always about investing millions of dollars in R&D, and there are plenty of opportunities for innovation even for the low-tech industries, which can yield significant economic impacts on the industries and a nation as a whole. Developing countries like Cambodia thus should not worry about making contributions to the technology frontier but instead should concentrate on using existing knowledge and technology and on assimilating it into the local context. Simply put, the country should focus on adopting and adapting the use of new technologies and knowledge, and in the case of research, applied research.

the use of new technologies and knowledge, and for the case of research, applied research.

3. Final remark

One might ask how we can increase the use of existing knowledge? This is difficult to answer but we would argue that Cambodia should instead try to increase the flow of existing knowledge found elsewhere into the country first. It can be done through multiple channels including human mobility, market transaction, international trade, and foreign direct investment, all of which increase the possibilities for spillovers. Hence, economic policies relating to market competition, trade, taxes, and private property can be implemented to incentivize international trade activities, foreign direct investment, and profit-maximizing firms to scale up their investment in R&D that drive technology and innovation (Howitt, 2010). However, it is not ideal to let only a few firms have a complete control over the market of technology and R&D, as at the same time, these firms can also exponentially increase and exploit their market power to influence the demand and supply. And we all have known what will happen in a market segment operated by a monopoly. Consequently, the development of STI driven by firms might occur at the expenses of the mass, and that scientific research is no longer done to maximize public welfare. In addition, science and technological improvement is also a type of social reform in the sense that social life has to evolve and adapt to the stage of technological development. For instance, smart phone is almost non-existent 20 years ago, yet it now becomes indispensable to our daily life. But reform, learning from historical experience, creates both winners and losers, and unfortunately history has also shown us that men are not good at compensating the latter. Thus, one needs to consider in advance the adverse effects and externalities of scientific development and innovation and how to compensate the losers created by such development.

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10 | CAREER POTENTIAL FOR YOUNG CAMBODIAN IN FINANCIAL TECHNOLOGY (FINTECH)

Mr. CHHAY Ravon

Master degree in Investment and Finance, Queen Mary University of London, United Kingdom

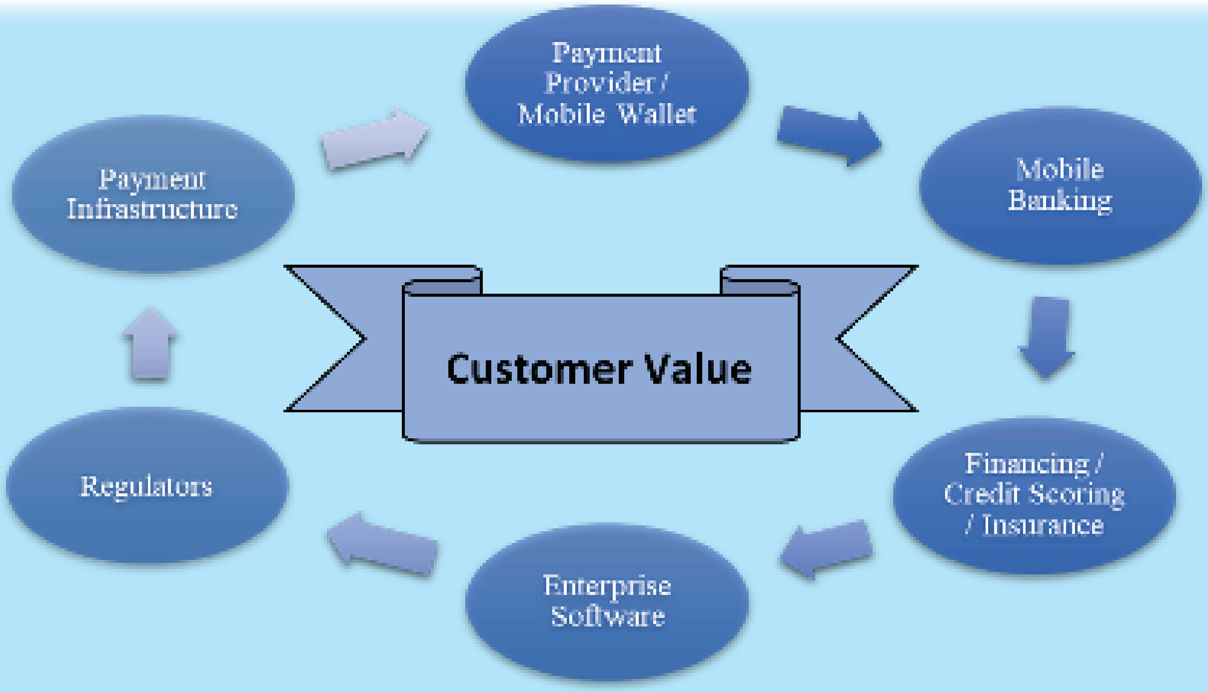

Figure 1. Selected Roles of Fintech within the Ecosystem.

Executive summary

Sustaining a long-term healthy growth economy is very important for every country's development. The Royal Government of Cambodia (RGC) realised that the workforce is one of the most important elements in maintaining a steady growth rate and prosperity. Therefore, to maintain and improve the competitiveness and seize the opportunities of the rapid technological and innovative evolution, the RGC has established policies and frameworks to prepare Cambodia for the transition into a digital economy country. Those policies and frameworks include developing, creating, and supporting young Cambodians with the ever-growing job demand, especially within the financial technology (Fintech) industry.

- Cambodia's Digital Economy Overview
- Fintech Ecosystem in Cambodia
- Prepare young Cambodians to meet the ever-growing job demands in the financial technology (Fintech) industry

1. Introduction

According to the Rectangular Strategy – Phase 4 and the Cambodia Vision 2050, as well as the readiness to prepare for the Fourth Industrial Revolution and digital transformations, the Royal Government of Cambodia (RGC) unveiled the "Digital Economy and Social Policy Framework of Cambodia 2021-2035" in May 2021, to help prepare Cambodia for the rapid technological evolution and to be ready to transform Cambodia into a digital economy country by 2023 (KHMER TIMES, 2021). This transformation of the economy will bring significant positive outcomes to the economy and society, especially new growth opportunities, an increase in productivity, and new career opportunities within the digital technology sector. After the establishment of the "Digital Economy and Social Policy Framework of Cambodia 2021-2035" policy in May 2021, the RGC formed the National Digital Economic and Social Council in September 2021, intending to promote and establish a digital economic foundation and social development for Cambodia. The RGC a has a vision and mission to "Build a vibrant digital economy and society by laying the foundations for promoting digital adoption and evolution in all sectors of society, the state, the people, and the business community" said Chea Vannak from Agence Kampuchea Presse (AKP) (KHMER TIMES, 2021).

2. Cambodia's Digital Economy

Nowadays, Cambodia has a high internet penetration as well as one of the youngest demographics in the region with a population of approximately 17 million and an average age of 25 years, which makes Cambodia become a fertile ground for the growth of the digital economy. According to the Mekong Strategic Partners data, it shows that Cambodia has just over 20 million mobile connections within the region which account for 124% of mobile penetration in the country (Phnom Penh Post, 2021). In addition, Cambodia has quite a high smartphone penetration with more than 10.7 million smartphones connected to the internet. Data rates are one of the cheapest in the area with an estimated 1 US Dollar for 10GB, regarding the 4G and 3G coverage in Cambodia there are around 80 percent and 85 percentage coverage out of the total population, respectively. With a high smartphone penetration within the country, it shows that by mid-2020 there were around 10.8 million Facebook users in Cambodia which account for 65% of the total population (Phnom Penh Post, 2021).

In 2019, Cambodia has a GDP growth rate of 7.1%, which is $26.9 billion in GDP and $1623 GDP per capita. In addition to that, there are opportunities and support for the MSME segment such as co-working spaces with more than 17 co-working spaces across Phnom Penh, the capital city of Cambodia (Phnom Penh Post, 2021). There are supported funds from both government and private sector, there are over 6 locally-based fund venture capital firms to support tech investment and startups. Currently, there are more than 300 active tech startups and more than 30 publicly disclosed startups in Cambodia. Cambodia's banking sector has rapidly developed over the last two decades which results in the improvement of safety and efficient payment system which helps accelerate the circulation of money among economic agents. Currently, there are more than 21 institutions that provide payment services. These tech startups and payment service institutions will result in increased job demand in the fintech industry (Phnom Penh Post, 2021).

According to Mekong strategic partners and raintree in 2018, there are more than 50 active fintech startups. Those active fintech startups include Pi Pay, BongLoy, SmartLoy, and many more where they provide services such as digital payments, Software as a Service (SaaS) for financial institutions, and digital banking.

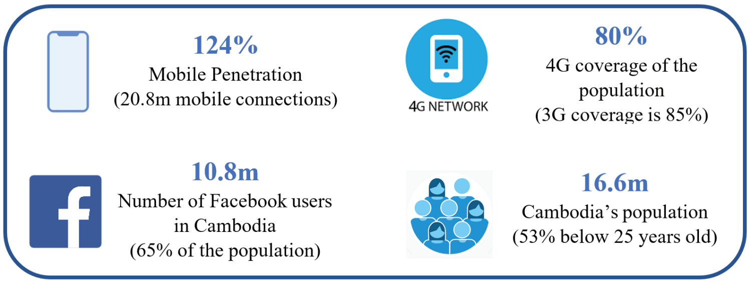

Figure 2. Overview of Internet Users in Cambodia.

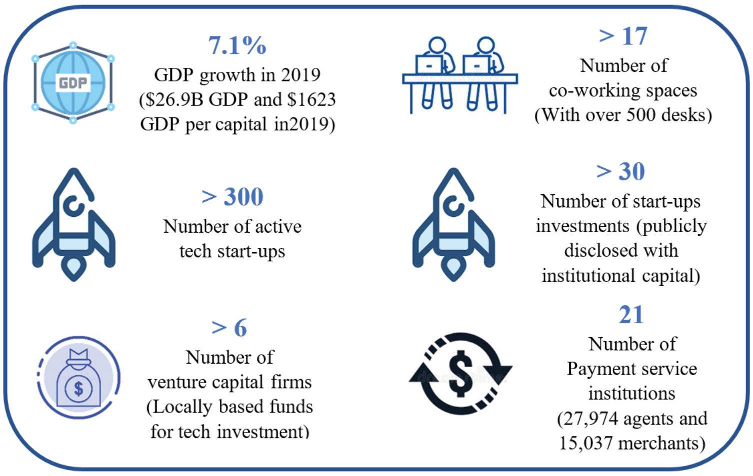

Figure 3. Overview of Cambodia's Digital Economy.

Figure 4. Actives Fintech Startups.

The ecosystem of Fintech is very diversified and can be described as dynamic with a complex network of agents that interconnect with each other to offer a wide range of financial products and services to end customers. In August 2020, the Mekong Strategic Partners has identified the roles of fintech and fintech players in the ecosystem which they formed to build and provide customers convenience, safety, access, and minimizing costs.

There are 6 important fintech key players within the ecosystems such as payment providers/mobile wallets; mobile banking applications; payment infrastructure providers; financing, credit scoring, and insurance; accounting and banking systems; and lastly regulators & supervisors. The role of payment providers or mobile wallets is here to ensure that merchants and consumers are connected smoothly for digital payment and to provide smooth transactions of money transfer and bill payments as well as provide other value-added financial services. The mobile banking application's role is to provide a 24/7 alternative service channel, to have a better understanding of client needs through mobile analytics, and maintain secured and better communications via in-app notifications as well as inter-connectivity of financial institutional partner distribution networks. The payment infrastructure provider's role is to provide a payment gateway to facilitate transactions from Cambodia and abroad, to provide the connection between banks and the network via the application programming interface (API) connector, to allow developers to issue cards within their application to their clients via card issuing API. The financing, credit scoring, and insurance role assist with assessing customer creditworthiness as well as facilitating digital loans and lowering the risk for the lender

Figure 5. Selected player of Cambodia's Fintech within the Ecosystem.

through various data analytics methods and support and offer digital insurance. The accounting and bank systems' role is to offer a core banking system, solutions for accounting financial reports, invoices, as well as inventory management. Last but not least are the regulators and supervisors, their role is to ensure that consumers are protected across every aspect of the value chain within the fintech industry, and to supervise and monitor those financial institutions and service providers for regulatory requirements, as well as to maintain integrity and confidence of the financial sector as a whole (KEM, CHEA & LENG, 2021).

Currently, the Royal Government of Cambodia is joining task with the private sector to help shape and prepare Cambodian youth for the high-demand job in the tech industry. In early December 2021, Huawei in Cambodia successfully conducted its 6th ceremony of "Huawei Cambodia Seeds for the Future 2021" and was presided by H.E CHEA Vandeth, Minister of the Ministry of Post and Telecommunications, and H.E WANG Wentian, Chinese ambassador of the Chinese Embassy in Cambodia. Mr. Sovann YAO, CEO of Huawei Cambodia expressed his support toward the "Rectangular Strategy" and the recently released

Figure 6. The "Seeds for the Future 2021" program.

"Digital Economy and Social Policy Framework of Cambodia 2021-2035" policy (KHMER TIMES, 2021).

In late August 2021, the Institute of Banking and Finance (IBF), and the Cambodian Association of Finance and Technology (CAFT) has signed a memorandum of understanding (MoU) with the Kirirom Institute of Technology (KIT) to help promote and improve the skills gap between the academic institutions' programmes and the fintech industry needs. This collaboration will provide the KIT students with majors that are aligning with the

Figure 7. promote the skills gap between the academic institutions' programmes and the fintech industry needs.

industry's expectations as well as having access to seek advice from Cambodian experts within the fintech industry. In addition to that, the IBF and CAFT will gain benefits through consultation with the KIT and a better understanding of the needs of their potential workforce as well as access to a pool of potential employees via various programmes such as internships and apprenticeships. With this MoU the "KIT disrupts the traditional learning model and replaces it with the experiential learning through projects and industry linkage to boost the students" said Leng Phirom the president of KIT. This will help prepare young Cambodians to prepare and be ready for the fintech industry (KHMER TIMES, 2021).

3. Conclusion

In conclusion, the RGC understands the importance of human resource development and creating job opportunities for young Cambodians within the fintech industry. The fintech industry has a large impact on Cambodia's digital economy development. There are policies and frameworks established by the RGC to help young Cambodians meet the ever-growing job demands in the fintech industry. As the industry constantly evolves and innovates, human resource development will continue to play a role in its development.

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OUR CONTRIBUTING WRITERS

Ms. VA SREYTHEA
Research assistant of Food Chemistry Lab, International University (IU)

Ms. KONG SOPHEAKTRA
Research assistant of Food Chemistry Lab, International University (IU)

Mr. CHONG ARECHKANG
Research Assistant of Food Chemistry Lab, International University (IU)

Ms. VANN KIMROEUN
Research assistant of Food Chemistry, International University (IU)

Dr. PHAN KONGKEA
Principle Investigator (PI) of Food Chemistry Lab, Faculty of Science and Technology, International University (IU)

Dr. UNG PORSRY
Director of Department of Science, Technology and Innovation Promotion and Development, National Institute of Science, Technology and Innovation (NISTI), Ministry of Industry, Science, Technology & Innovation (MISTI)

Mr. SOTH SEREYBOTH
Officer of Department of Science, Technology and Innovation Training, National Institute of Science, Technology and Innovation (NISTI), Ministry of Industry, Science, Technology & Innovation (MISTI)

Dr. SIEV SOKLY
Deputy director of Department of Science, Technology and Innovation Policy, Ministry of Industry, Science, Technology & Innovation (MISTI)

Dr. SENG TOUCH
Deputy director of Department of Science, Technology and Innovation Policy, Ministry of Industry, Science, Technology & Innovation (MISTI)

OUR CONTRIBUTING WRITERS

Mr. TRY SOKKEANG
Head of STI Support Office, National Institute of Science, Technology and Innovation (NISTI), Ministry of Industry, Science, Technology & Innovation (MISTI)

Ms. HEANG NGECH HORNG
Head of STI Promotion Office, National Institute of Science, Technology and Innovation (NISTI), Ministry of Industry, Science, Technology & Innovation (MISTI)

Dr. SRUN PAGNARITH
Director of Department of Science, Technology and Innovation Policy, Ministry of Industry, Science, Technology & Innovation (MISTI)

Dr. CHEAT SOPHAL
Director of Department of Policies Monitoring, Inspection and Evaluation, Ministry of Industry, Science, Technology & Innovation (MISTI)

Mr. SOEUR CHUMNITH
Officer of Department of Policy Monitoring, Inspection and Evaluation, Ministry of Industry, Science, Technology & Innovation (MISTI)

Ms. ING CHANDAVYA
Associate of Tilleke & Gibbins (Cambodia) Ltd.

Dr. CHEA VATANA
Director of Research and Innovation at the Cambodia University of Technology and Science (CamTech)

Ms. ING SOPHEAP
Research Assistant, Cambodia University of Technology and Science (CamTech)

Mr. CHHAY RAVON
Deputy director of Department of Science, Technology and Innovation Promotion and Development, National Institute of Science, Technology and Innovation (NISTI), Ministry of Industry, Science, Technology & Innovation (MISTI)

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