Connecting Computational Thinking (CT) Concept with the Game-Based Learning (GBL) Elements

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Abstract—This study aims to identify the game-based learning component (GBL) and the concept of computational thinking (CT) that can be integrated together in a design model. GBL and CT concept components are obtained through analysis of previous research and specialist consultancy. The method of analytical analysis consists of three phases i.e. planning, implementation and documentation. This analysis started on March to May 2020 and involved 398 articles related to GBL and CT. However, there are only fifteen articles on the development element of the GBL application and eight articles related to the CT concept were used. During an expert consultancy, fifteen specialists was involved in various backgrounds and experience in GBL and CT. The result shows that there are six main elements and 21 sub-elements of GBL. 6 main elements consist of rules, objectives, feedback, interactions, challenges and narrative. Mean-while, the sub-element consists of the operating rules, basic rules, explicit rules and behaviours, measures, goals, gamification purposes, marks, re-wards, badges/awards, player charts, characters, consequences, constraints, levels of games, fun, competition, control, space, engagement and curiosity that have been matched with their main elements. The main element and sub-element of the GBL is called GBL component. Each of these GBL components is integrated with seven concepts of CT i.e. decomposition, algorithm, abstraction, logical reasoning, assessment, evaluation, pattern recognition and automation.

Keywords—game-based learning, computational thinking, design model

1 Introduction

A game-based learning (GBL) application has long been used in the educational system since it was introduced by Marc Prensky in the early years of 2000 [1]. Many studies proved that the GBL elements can encourage student's involvement and motivate them naturally to learning [2, 3, 4, 5]. Thus, some studies have introduced models and frameworks to develop GBL applications for the purpose of teaching and learning;

including New Model of Flow [6], Rapid Digital Game Creation [7], Human Centered Design Methodology [8] and many more.

In addition, the computational thinking (CT) concept has also been a focus on some studies lately [9, 10]. Earlier, Wing [11] defines CT as a mental activity in formulating problems through a computational solution that can be done by human or machines, or with a combination of human and machinery. In the study of [12, 13] in 2012 noted that they have developed a GBL framework which allows students to dominate some CT skills during play. The skills intended are:

1. Create and use algorithms to resolve specific problems.
2. Assess an algorithm by specifying the appropriate criteria.
3. Using the CT method to problems.
4. Debugging algorithm and detects logical errors.
5. Simulated algorithms and observe the effects that need to be considered in the scaling skills.

The findings of their study clearly showed a positive effect and relationship between GBL and CT which is also supported by [14, 15]. Hence, this study aims to identify what are the GBL elements and the CT concept suitable to be integrated into a design model of GBL application development.

2 Game-based learning

GBL is a computer based teaching and learning approach which has been developed along with the advent of the computer technology since 1950s. According to Prensky, [1] the early computer game history was started by the US military and Gredler [16] states that it was used as a simulation tool to advance the military strategic planning. Various researches show that GBL has its advantages in supporting student's learning [17, 18]. For examples, Gee [19] and Mims [20] noted that GBL offers challenging experiences, promotes intrinsic satisfaction and gives students real learning opportunities. This happens when they are exploring the game environment with excitement and risk-free manner [21]. In fact, studies proved that GBL increases student's personal achievement which leads to higher academic records [22, 23]. Therefore, it is no doubt that higher educational institutions are those parties which apply this method the most since 2001 until now [24].

Meanwhile, Anderson, [25] explains the way how games could open up a more exciting way of teaching and learning. Based on Figure 1, there are eight aspects of game whereby the main aspect is that a game should be fun enough to the player. Another aspect is that the character which dictates the way a player involves in the game should be clearly stated (roles and characteristics) and holistically and practically shown throughout the game. In every games, there should be goals and objectives to

attain after a series of matches or competitions between the main character and the game settings. Hence, the nature of the competitions in the game should be carefully created to enhance a player's skills in strategy building, problem solving and thinking speed. The player masters most of these skills unconsciously while playing passionately to obtain rewards in the game [64].

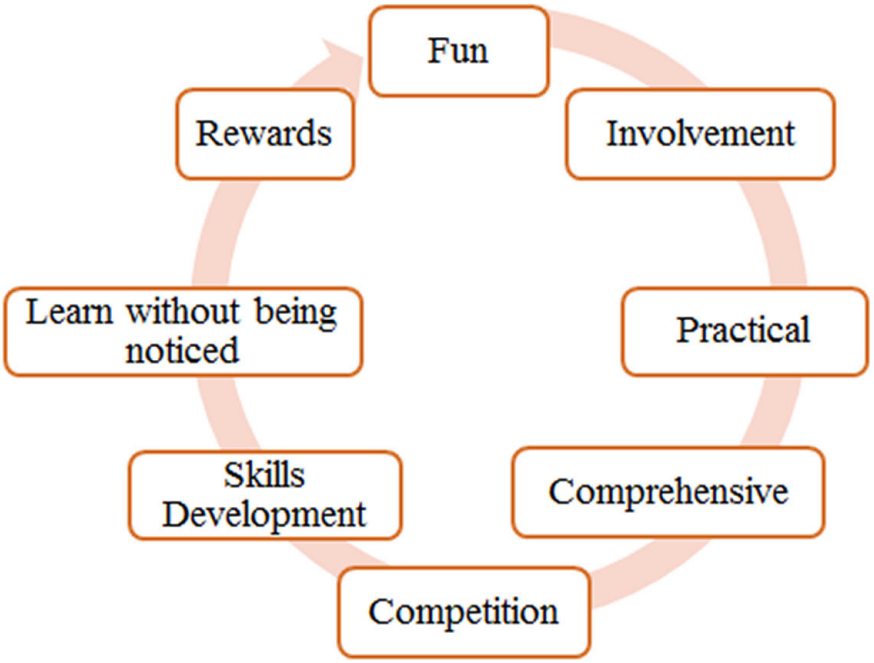

Fig. 1. Aspect of GBL in education [25]

2.1 Elements of GBL

Prensky, [26, 27] suggests three classical elements in a game as follows: rule, goal or objective and ending or feedback. According to him, these three elements form the basis for game structures and are used to differentiate all types of game. In GBL context, he modifies the elements into six types, namely rule, goal, feedback, interaction, challenge and narrative. Figure 2 explains that the three main elements in a game are rule, goal and feedback whereas interaction, challenge and narrative are the optional elements in a game. The use of these elements depends on the way of playing and the design which formed a game structure. While Table 1 shows Hoe's [28] explanation for each GBL elements.

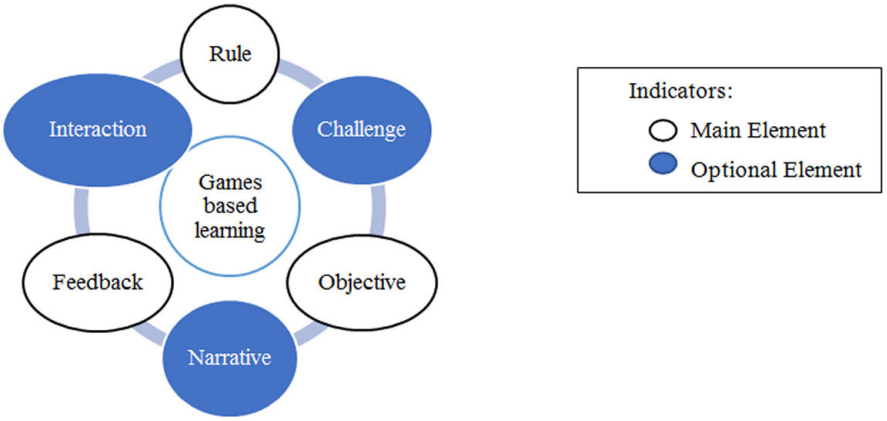

Fig. 2. Main and optional elements in GBL structure [26, 27]

Table 1. Explanation of GBL elements [28]

GBL Elements	Explanation
Goal	Goal is the target, objective or purpose in a game. It differentiates between games and toys. Goal can be regarded as the first rule in a game.
Rule	A set of instructions which controls the internal structures of a game and it becomes the main determinant of the game quality. Explaining players' action is also a rule.
Feedback	Feedback is the information given to players whether formatively or summatively based on the players' action.
Challenge	An obstacle which forms a game and consists of certain difficulty levels in accordance with a player's level of knowledge, skill and progress in the game.
Narrative	Narrative is the basis for players' involvement in a game. Without the storyboard, a player is unable to play his role well as it is an important determinant for learning to occur.
Interaction	Interaction is a relationship or reaction which involves two situations either between a player and the game settings or between a player and other players.

Teaching-based game design increasingly popular especially in attracting student's interest in computer science specifically. This is because design methods are flexible and provide opportunities for students to explore new learning strategies. There are several studies that have introduced models and frameworks for their GBL development. A study by [12] stated that they have developed a game framework that allows students to dominate some skills during playing games. The skills are:

1. Creates and uses algorithms to solve specific problems.
2. Assess an algorithm by specifying appropriate criteria.
3. Using the CT concept to solve the problem.
4. Debugging algorithm and detects logical errors.
5. Simulated algorithms and observe the effects that need to be considered in abstraction skills.

3 Computational thinking (CT)

CT term was first introduced by Papert in 1980 towards the development of cognitive ability in problem solving through the programming language [29]. The term grew out of the pioneering work of Papert and colleagues on design-based constructionist programming environments; where it refers to ways of algorithmically solving problems and to the acquisition of technological fluency [30]. Then, in 2006, Wing had broaden the CT concept by stating that CT is a basic skill for everyone and is relevant in all fields [31, 63]. The skill of CT was initially adopted as the basic field of computer science in solving problems, designing systems and understanding human behaviors. Nowadays CT skills were employed widely and Wing, [32] says that almost everyone is thinking like a computer when applying CT concept. In fact, concept of CT assists people in a smooth problem solving [33] and it should be regarded as an essential skill for the 21st Century [34, 35]. Mohaghegh and Mccauley, [36] support the idea asserting that CT concept is a skill which is closely related to the 21st century skills such as problem solving, critical thinking, productivity as well as creativity and thus, should be adopted by every students. Wing [11] in his study, lists down the common characteristics of CT which illustrate CT promotes various thinking processes in order to solve problem:

1. The stress is on CT as a concept instead of a programming which is not limited to the field of computer science.
2. The importance of basic skills rather than mere memorization that it is based on executable solving method through machine, human or a combination of both.
3. A way of human thinking and not computer processing because human thought is more powerful than a computer which is a product of a systematic thinking process by human.
4. A complement and a combination of mathematical thinking idea and non-artifact engineering. In fact, CT is an integrable thinking process in all fields for everyone anywhere.

Barefoot Computing, which is based in the United Kingdom also pointed out six main concepts of CT [37]:

1. Decomposition: A big and complex task is broken down into several smaller detailed tasks to make it more comprehensible for a human or computer.
2. Pattern: The ability to identify common similarities and differences in a task or problem to make a prediction about a solution or to find an immediate solution.
3. Abstraction: The ability to filter out unneeded information to solve problem and to generalize the information when necessary.
4. Algorithmic: The ability to build a step-by-step strategy to solve problem.
5. Logical reasoning: The ability to think logically and to determine a specific conclusion (deduction) based on the available information.
6. Evaluation: The ability to ensure an accurate outcome is obtained based on the actual need and to think about its improvement.

4 Methodology

In order to identify the relevant GBL elements and CT concept for integration into a designed model of GBL application, this study utilized two research methods namely a comparative analysis of previous studies, and expert consultation. This study conducted the comparative analysis of previous studies by critically analyze the elements of GBL and CT concept as well as other related factors. At this stage, all data of the associated factors and elements concerning the GBL and CT concept was collected and organized to be included into an integrated model for designing and developing effective GBL applications.

A Kitchenham's method [38] of comparative analysis of studies was employed which includes three main phases namely, planning, execution, and documentation. Table 2 shows the related phases and specific activities conducted in this method to achieve the study objective.

Table 2. Systematic survey phases

Phase	Method
Planning	Specific research questions
	Build survey guidelines
	Confirm survey guidelines
Execution	Identify relevant studies
	Select the main research
	Evaluate the research quality
	Extract the necessary data
	Synthesize the data
Documentation	Write the survey report
	Confirm the survey report

In this study, the main terms, namely "Computational Thinking" and "Game based Learning" was searched. Additionally, the second level terms namely "school", "secondary school", "primary school", "advantages", "evaluation", and "assessment" were also checked. Several suggested research selection criteria for the systematic analysis were set. They are as follows:

1. Answer one or more research questions directly.
2. Associated with the teaching of GBL and CT at any educational institutions.
3. A specific computerization or computer science course or module which focus on problem solving through CT and GBL.

In the second method which is experts consultation, fifteen experts were consulted to obtain divergent ideas, the expert's views on the concept and their reviews concerning the referred research materials. Table 3 indicates the data of the involved experts.

Table 3. Experts demography—expert consultation phase

Position	Institution/ Department	Experience (No. of Years)	Field	Total
Head of Department	Institute of Teacher Education	21–25	Educ. Technology	1
		16–20	Info. Technology	1
Senior Lecturer	Institute of Teacher Education	21–25	Info. Technology	2
		21–25	Computer Science	1
		21–25	Educ. Technology	2
Lecturer	Institute of Teacher Education	21–25	Info. Technology	2
		16–20	Educ. Technology	2
		11–15	Education	1
		16–20	History	1
Officer	State Education Department	11–15	Computer Science	1
ICT Teacher	School	16–20	Computer Science	1
Total				15

Every given inputs and feedbacks by the experts were evaluated and used where necessary. The number of consulted experts is comprised of those CT master trainers who participated in Malaysia Digital Economy Corporation (MDEC) courses and involved in the development of the Scratch-based game applications. In addition to that, all of the chosen experts are the facilitators of CT related courses at the Institute of Teacher Education (IPG) and State Education Department (JPN) of Malaysia. The experts demography of various experiences and expertise are very useful for data gathering. The questionnaire forms are distributed earlier before conducting the consultation. Through the questionnaire, the selected experts would be well informed about the intended purposes of this study.

5 Research findings

Online searches for articles and research findings from the databases as listed in Table 4 were done between March until May 2020.

Table 4. Number of selected articles

No.	Databases	No. of Selected Articles
1	ACM Digital Library	187
2	IEEE Xplore	73
3	ERIC	8
4	Google Scholar	130
Total number		398

These articles were then studied and analyzed based on certain criteria. Out of 398 articles only a few articles accepted as the major references for determining GBL component or element and CT concept. These articles selection consideration is based on;

1. The study must be relevant to the GBL application development. However, related articles on the development and the use of digital games are also re-evaluated to determine game elements.
2. Studies concerning CT dan CT concept application. Articles which explain CT concept and its development were also examined to reach a better understanding about CT skills in many fields.
3. GBL and CT related studies. There are very limited articles with this term as there is a lack of studies in this regard abroad or in Malaysia.
4. The duration of the studies been conducted. The selected articles are from the studies conducted within the last 10 years. However, the original GBL and CT studies were referred as important sources.

Overall, there are 15 related articles on the element of GBL application development and 8 articles associated with the concept of CT in GBL were referred. These articles were analyzed to identify GBL model components for CT. Based on the analysis, there are several studies use the main GBL element terms which are matched with another additional terms to support the elements. Apart from that, there is a situation whereby the main elements in research A are regarded as sub-elements in research B. Therefore, in this research we use the term of GBL components to avoid confusion. Table 5 indicates the result of the GBL component analysis. While in Table 6 describes the GBL components and its frequency scores as indicated in the previous studies.

Table 5. Analysis of GBL components from previous studies

Sources	Components												
	A	***B***	***C***	***D***	***E***	***F***	***G***	***H***	***I***	***J***	***K***	***L***	***M***
[39]	/	/		/			/					/	
[40]			/		/				/				/
[41]	/	/		/			/						
[42]					/				/				/
[43]	/	/									/		/
[44]	/	/	/	/	/	/							
[45]								/		/	/		
[46]					/			/	/				
[47]	/		/	/	/	/							
[48]	/	/	/	/	/				/		/	.	/
[49]	/	/	/		/		/						/
[50]					/				/	/			/
[51]		/	/		/	/							
[52]					/				/	/			/
[26, 27]	/	/	/	/	/	/							

Table 6. Description of GBL components and its frequency scores

Components		Frequencies in Previous Studies
A	Rule	8/15
B	Goal	8/15
C	Feedback	7/15
D	Interaction	6/15
E	Challenge	11/15
F	Narrative	4/15
G	Gaming Space	3/15
H	Engagement	2/15
I	Rewards	6/15
J	Motivation	3/15
K	Fun	3/15
L	Character	1/15
M	Level	7/15

On the other hand, based on Table 7, the data shows that there are fewer related researches on the term CT concept particularly the one which is integrated into GBL. Since its introduction in 2006, most of the studies are about the definition and importance of CT as a curriculum in the 21st century education. Fewer researchers describe the main CT concept in their studies until the Computer Science Teachers Association (CSTA) and the International Society for Technology in Education (NSTE) begin their first steps in 2011. However until 2018, the analysis shows that there are differences in the way the CT concepts are used in the researches. This is due to the differences of the fields and the country where the researches were conducted. Furthermore there are several CT concepts which are no longer used in recent studies when there is a clearer definition of CT as understood and agreed upon by the experts of academic and technology. Table 7 shows that abstraction, decomposition and algorithmic are the CT concepts used in all studies. This proves that the three concepts are important concepts for CT. This is followed by the concept of automation and evaluation with the frequency value of 5 and 3 respectively. While Table 8 describes the CT concepts and its frequencies in previous researches related to GBL.

Table 7. Analysis of CT concepts in GBL researches

Sources	Concepts															
	A	***B***	***C***	***D***	***E***	***F***	***G***	***H***	***I***	***J***	***K***	***L***	***M***	***N***	***O***	***P***
[52]		/	/	/			/	/								
[53]	/	/	/	/	/	/			/							
[54]		/	/	/												
[55]	/	/	/	/	/	/										
[56]		/	/	/	/	/		/		/						
[57]	/	/	/	/		/										/
[58]	/	/	/	/							/	/	/	/	/	
[59]	/	/	/	/							/	/	/	/	/	

Table 8. Description of CT concepts and its frequencies

Concepts		Frequencies in Previous Studies
A	Automation	5/8
B	Abstraction	8/8
C	Decomposition	8/8
D	Algorithmic	8/8
E	Evaluation	3/8
F	Generalization	4/8
G	Reflective Thinking	1/8
H	Patterns Recognition	2/8
I	Thinking Process	1/8
J	Logical Reasoning	1/8
K	Data Collecting	2/8
L	Data Analysis	2/8
M	Data Presentation	2/8
N	Parallelization	2/8
P	Simulation	2/8

From the conducted analysis, we found that these CT concepts can be expanded and improved by the researchers. This study also indicates that it is rational for us to choose any CT concepts to use in our study. The findings clearly show that CT concepts are usable independently or can be combined freely and they are not restricted under any particular conditions. To obtain a stronger support, the researcher consulted the experts using this finding as a basis.

5.1 Findings from the expert consultation

The first step in reaching expert's agreement on the GBL components and CT concepts is through counting the number of experts who agreed or disagreed collectively towards each items. The score for accept (agree) or reject (disagree) regarding the GBL components and the CT concepts is counted based on their feedbacks towards five answer choices (1- strongly disagree, 2- disagree, 3- mildly agree, 4- agree, and 5- strongly agree) for each items. An expert is considered agrees to accept an item if he responds by choosing 3, 4 or 5. Likewise, he or she is regarded as declined if he responds 1 or 2 to an item.

The second step is to determine selection condition (accept or reject) of the GBL components and the CT concepts. The condition is set to affirm the collective agreement of expert's opinion in the conducted consultation. If the score is 10 to 15, it shows that the component should be considered to be acceptable, score 5 to 9 may be considered whether it is accepted or rejected and if the score record is below 5 the component may be omitted (rejected). The findings of the comparative analysis of the previous studies and the expert consultation try to answer the research question; "*Could the GBL components and the CT concepts be integrated into a designed GBL model?*"

GBL components and the CT concepts are shown in Table 9 which refers to the divided GBL components of two parts namely main elements and sub-elements.

Table 9. GBL components—experts consultation resolution

GBL Components		No. of Experts Agreements	Resolution / - Accept X- Reject
Main Elements	**Sub-elements**		
Rule	Operational Rules	15/15	/
	Basic Rules	15/15	/
	Implicit Rule & behaviors	12/15	/
	Instructional	15/15	/
Objective	Goal of the game	15/15	/
	Gamification Purposes	10/15	/
Feedback	Marks	15/15	/
	Rewards	15/15	/
	Badges/gifts	8/15	/
	Player Chart	10/15	/
Interaction	Character	13/15	/
	Competition	6/15	X
	Effect	14/15	/
	Mark	0/15	X
	Rewards	0/15	X
Challenge	Obstacle	15/15	/
	Game Level	15/15	/
	Motivation	4/15	X
	Fun	13/15	/
	Fight	9/15	/
	Control	13/15	/
Narrative	Space	15/15	/
	Engagement	15/15	/
	Character	2/15	X
	Story board	3/15	X
	Curiosity	14/15	/
	Rewards	3/15	X

There are six main elements which form a GBL and they are interpreted through sub-elements. These sub-elements are optional for a designer to use in developing their intended GBL application. In other words, there is no condition or it is permissible for a designer not to use all GBL components simultaneously in a game application. Challenge is a main element with many sub-elements. The existence of more sub-elements gives the GBL designers more choices in terms of harnessing their game application through a new technology. In addition, another important main elements with four sub-elements are rule and feedback. These expert-agreed elements are usually used in various GBL genre. This is followed by narrative which consisted of three sub-elements as well as objective and interaction with two sub-elements respectively which are very useful for GBL designers.

While, Table 10 shows the seven CT concepts which were agreed by the experts to be integrated with the GBL components into a designed model of GBL. The list in the table indicates the level of agreement whereby all involved experts agreed on decomposition, abstraction, algorithmic, logical reasoning and evaluation. At the meantime, some of them had slightly different views on pattern recognition and automation.

Table 10. CT concepts—experts consultation resolution

CT Concepts	No. of Experts Agreement	Resolution (/ - Accept, X- Reject)
Decomposition	15/15	/
Patterns Recognition	13/15	/
Abstraction	15/15	/
Algorithmic	15/15	/
Logical Reasoning	15/15	/
Evaluation	15/15	/
Automation	11/15	/
Generalization	5/15	X
Reflective Thinking	5/15	X
Thinking Process	5/15	X
Data Collecting	5/15	X
Data Analysis	5/15	X
Data Presentation	6/15	X
Parallel	6/15	X
Simulation	5/15	X
Debugging	6/15	X

6 Conclusion

In answering the research question that is to identify the GBL components and the CT concept which can be integrated into a GBL designed models, we conducted initial analysis through comparative study of previous researches as well as experts consultation. The implementation of both methods has been mentioned in research methodology part. Shanmugam, Yassin, and Khalid [60] also utilized these method in research to determine relevant CT elements for integration into the life cycle model of mobile application development (MADLC). After the experts consultation, the researcher identified six approved main elements and twenty sub-elements of GBL and they are matched accordingly as in Table 11. For CT concepts, there are seven affirmed concepts as illustrated in Table 12. Most of these CT concepts are almost similar to Shanmugam's [60] except for logical reasoning and automation.

Table 11. Game based learning (GBL) components

GBL Components		
No	**Main Elements**	**Sub-elements**
1.	Rule	Operational Rule
		Basic Rule
		Explicit Rule and Behavior
		Instructional
2.	Objective	Game Goal
		Gamification Purpose
3.	Feedback	Mark
		Reward
		Badge/medal
		Players Chart
4.	Interaction	Character
		Effect
5.	Challenge	Constraint
		Game Level
		Fun
		Competition
		Control
6.	Narrative	Space
		Engagement
		Curiosity

Table 12. CT concepts in GBL

No	CT Concepts
1.	Decomposition
2.	Abstraction
3.	Algorithmic
4.	Logical Reasoning
5.	Evaluation
6.	Pattern Recognition
7.	Automation

Through this study, GBL component terms which consist of main elements and sub-elements were introduced. Both terms were not used or clearly defined in previous researches [61]. The terms usage is approved during the consultation due to their relevance and easiness in justification while building the future model. Apart from that,

we affirmed seven relevant CT concepts for integration into GBL components instead of other several CT concepts in the previous studies. We also propose expert-approved standardized terms definition for GBL components and CT concepts as discussed in research findings part. Hopefully the definition may assist designers and researchers in identifying the terms difference and usage in developing GBL application [62]. For further researches we stress on three matters, the first thing is the need for a research study to build a designed model of GBL to learn CT especially for students based on the newest technology. Another suggestion for research is related to efforts of enhancing students CT skills through GBL application development and continuous improvements in classroom pedagogical practices based on GBL. It is hoped that this research findings may be beneficial for all parties particularly the MOE, researchers, industries and many more.

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