A Mobile Game-Based Learning Approach for Motivating Preschoolers and Primary Students in Learning Mathematics

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Abstract. Learning in an interesting and funny way is a successful key for little kids to absorb new concepts. In Hong Kong, kids are studying core subjects through "assessment" as they have to prepare for their standardized tests and examinations. Most of them are studying under high pressure to obtain excellence in the assessment. If they did not get good results, they will be frustrated and will lose their interest in learning eventually. This paper introduces the use of "game-based learning" for little kids to learn simple arithmetic calculations in a funny way. By using artificial intelligence (AI) techniques, the application can provide training exercises casually to motivate kids to learn simple arithmetic during the gameplay. Kids are focusing on how to defeat the monsters to satisfy the game goal that they will work hard to solve the simple mathematical questions. Also, the application can enhance the parent-child relationship when the kids achieve the goal in each stage with their parents together.

Keywords: Online learning · Quality assurance · Student engagement · Student satisfaction

1 Introduction

The Hong Kong Government provides 12 years of free primary and secondary education to children studying in public schools (Education Bureau 2020). In addition, a "Free Quality Kindergarten Education" (Education Bureau 2016) was released from the academic year[1] 2017/18 that the government will provide financial support to all families with their children admitted to non-profit based kindergarten.

In Hong Kong, students have adopted to study through different types of "assessment" as they have to prepare for a lot of standardized tests and examinations, especially for primary students. To achieve academic excellence, kids are studying in high pressure with many extra-curricular activities. They will face with many "intrinsic" punishments,

[1] In Hong Kong, "academic year" means the period from the first day of September to the last day of August in next year.

L.-K. Lee et al. (Eds.): ICTE 2020, CCIS 1302, pp. 35–45, 2020.
https://doi.org/10.1007/978-981-33-4594-2_4

such as physical punishment from parents (Chu 2018) if their results are not good enough (Topick - Hong Kong Economic Times 2018). Hence, some children may get frustrated and lose their confidence in learning. The worst case is some children cannot afford the pressure and commit suicides (Ngan 2019). The committee on Prevention of Student Suicides by the Education Bureau (Committee on Prevention of Student Suicides 2016) stated there is over 55% of investigated cases that are related to study problem.

Moreover, the main pedagogy used in Hong Kong education is a "spoon-feeding education" instead of "student-based education". Students are forced to "absorb" all the knowledge to satisfy all the requirements released by Education Bureau (Curriculum Development Council 2014, 2017), which may not be an effective way for students to learn. Even though the educational reform has been proposed in recent years, such as acquiring information technology and activity-based education, the fundamental education system of Hong Kong remains the same. A known protocol for teacher is to complete the syllabus on time that they are hard to take care of the student affordance and the learning quality. The Legislative Council committee (2009, 2010) pointed out that the current education system remains an outdated "spoon-feeding" which focused on "memorization" and "rote". With this approach, creativity from students will be minimal.

To motivate children in learning, stakeholders should promote more innovative ways than using the traditional teaching methodology in conducting lessons as the children in this generation need more attention than before. Also, many supports and supplementary activities are proposed by applying various technologies. Lee et al. (2019) proposed a mobile game with an attractive interface in learning English vocabularies by building models with virtual Lego blocks in using AR technology. The application can let users learn English words effectively in a funny way by building blocks virtually.

In this paper, a simple game application is proposed to motivate preschoolers and junior primary education students to learn simple mathematics by completing simple tasks in an interesting game with attractive interface. In enhancing the efficiency and correctness in mental arithmetic, dynamic practicing is an effective way to realize the preferred results. Hence, the application contains an arena so the user can control the player character to collect all required resources by purifying enemies with mental arithmetic skills as the weapon. The user can then activate the attack mode to damage the stage boss or the healing mode to protect the character by answering a mathematical question involves arithmetic calculation. This process will be repeated until the stamina of the stage boss is used up. The game will be continued to the next level. The gameplay can attract the kids to complete all stages. Moreover, not just for improving the mental arithmetic skill, the application also aims to improve the parent-child relationship as parents should accompany their child to manage the game adventure.

2 Literature Review

The application will be web-based and compatible with computers and mobile devices in choosing appropriate technologies, there will be a definite advantage which satisfies the requirements in both computers and mobile devices. In the following, Sect. 2.1 will review the current technologies, and Sect. 2.2 will review similar applications available in the market currently.

2.1 Review of Technologies

Review of Programming Languages. There are many web-based technologies such as JavaScript, Hypertext Preprocessor (PHP) and Python, which can be applied to build up web applications. However, the requirements of those languages other than JavaScript are high. For example, PHP has to be operated by a server. However, JavaScript can be used to build applications in either client-server mode or standalone mode. Also, JavaScript can be applied with Hypertext Markup Language (HTML) together easily. Curran and George (Curran and George 2012) evaluated the usability of JavaScript with other techniques for building up different types of web game applications. By applying JavaScript APIs, it can enrich the functionality of the game to increase the gaming experiences.

Review of Artificial Intelligence (AI). To enhance the gameplay of the game, AI techniques can be applied to the game. Pannu (2015) explored the standard AI techniques in use, such as Neural Network, Fuzzy Logic, Evolutionary Computing, and Hybrid Artificial Intelligence. The mechanism of each technique and the related area was discussed in detail. In this paper, AI algorithm will be explored, but the AI algorithm cannot be "too clever" to defeat the player while most of the users are the kids, and they have limited calculation ability. Kids may be frustrated if the AI enemies defeat them by generating complicated questions.

2.2 Review of Existing Solutions

Zhang et al. (2004) compared the pros and cons of classroom learning and e-learning. The assessment results by using e-learning are much higher than that of classroom learning. They concluded e-learning could perform effective teaching and learning environments for both students and teachers. Moreover, the traditional classroom learning needs students to attend the class according to a specific time and a designated location. It leads to the lack of flexibility for students to learn at anytime and anywhere. Also, the instructors need to complete the teaching at a designated place and time.

Pareto (2012) proposed an application by using AR in performing arithmetic. The application mainly focuses on students with disability that provides many activities for students to cope with their difficulties. This AR application may not be suitable for mental arithmetic because our targeted users are different. Moreover, a relatively larger space is needed to run the AR application.

Roussou et al. (2006) proposed a virtual reality (VR) application in education. However, VR is not suitable for kids, especially for kids aged 3–8; it may be harmful to their eyes. The application needs to prepare ample space to perform the activity with VR googles. The VR application is not suitable for nursery and junior primary students since they may feel dizzy when they play with VR googles. Shields and Wells (N.D.) reported that using VR headset may cause headaches, eye strain, dizziness and nausea, and myopia. Sony Interactive Entertainment Inc[2] stated the health warning that their VR device is not suitable for children aged under 12.

[2] https://www.playstation.com/en-us/network/legal/health-warnings/

Baldeón et al. (2015) proposed a game application to let kids to learn mathematics through a role-playing experience. The game is exciting that the player can become a game designer to build up a series of games for other in learning fractions. The game is strategically focusing on the children who like designing games. Teacher is the supervisor to monitor the whole development. In Hong Kong, few kids are smart enough to perform the game development, especially for preschoolers. Also, parents are hard to approve their children to learn core contents in an indirect way.

3 Methodology

3.1 Application Design

Game Interface Design. Since the users are preschoolers accompanied with their parents, the game interface should be simple engaging and colorful to attract the users. Moreover, the interface design is in responsive according to the different devices in use. The application will automatically determine the operating device to provide a consistent gaming experience. Alternatively, it provides the best fit of the screen display which satisfies the requirements of the device.

Game Play Design. In each stage, there is an arena with a stage boss to be defeated by the player by collecting a number of gems (resources). In each turn, there are several monsters at different places. The player should meet all monsters in the arena to collect the resources. When the player meets a monster, an arithmetic question will be prompted, it can be an addition, a subtraction, or a mixed arithmetic question with addition and subtraction, according to the level of the game, as shown in Fig. 1. Then, the player should select the correct answer to solve the question, and the resource can be collected by purifying that monster if the player answers the question correctly. If the player gives a wrong answer, the stamina of the player will be deducted, and the monster leaves the arena immediately. When all monsters are defeated or left, that turn will be completed. In each turn, several resources can be collected only. When the player collected the required number of resources (it can be in several turns), the player can activate the attack mode to attack the stage boss by solving a relatively complicated arithmetic question, commonly in mixed arithmetic to reduce the stamina of stage boss, as shown in Fig. 2, or activate the heal mode to recover the player stamina as shown in Fig. 3. If the stamina of the player or stage boss has not been used up, next turn is prompted to collect resources then attack the stage boss until the stage boss or the player has been defeated. Then the game advances to the next stage if the stage boss is defeated or the game is over when the player is defeated. When the game is over, the overall statistics of each gameplay will be displayed, as shown in Fig. 4.

As kids may not be familiar in using the attack mode or heal mode, the game will determine the suitable mode based on the stamina of the player; if the stamina is 80% or more, only attack mode can be activated. On the other hand, only heal mode can be activated when the stamina of player is less than 20%.

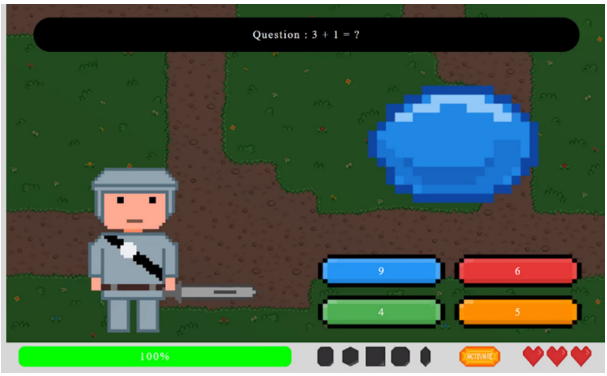

Fig. 1. An arithmetic question is prompted when the player (player) meets the monster (NPC).

Fig. 2. The attack mode with a complicated question in defeating the stage boss.

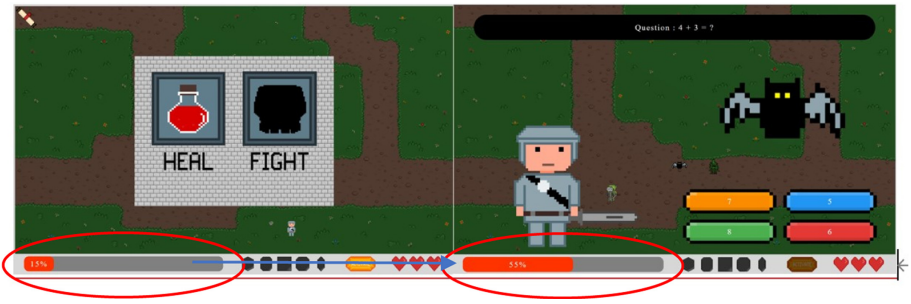

Fig. 3. The player stamina is recovered by heal mode.

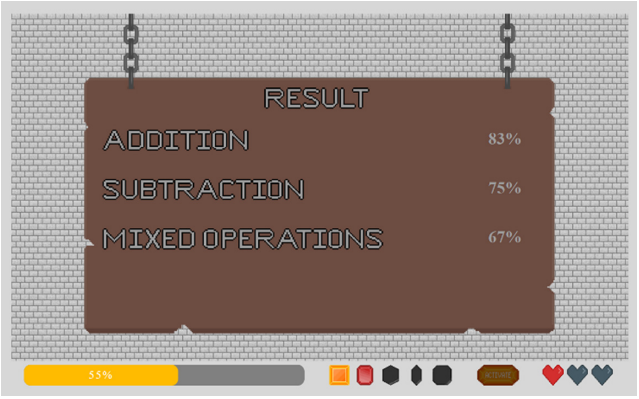

Fig. 4. The result page of the game application.

3.2 Character Movement Design

In the game, except the stage boss, all characters included player character (player, PC), and non-player characters (monsters, NPC) can move freely within the arena. There are policies to perform the best movement of the player and all monsters.

Since the game can be applied either on laptops or mobile devices, the user controls the player by keyboard may not be suitable because there is no external keyboard installed on a mobile device. Moreover, the virtual keyboard in the mobile device is not appropriate since the virtual keyboard covered around one-third of the screen, so the arena is covered then the gameplay will be affected. So, a direct position allocation mechanism is applied by using a mouse (mainly for laptops) or directly click the place of the arena (mainly for mobile devices or laptops with touch screen function) to schedule the route of character. The turning angle of the character will be calculated by using formula (1) when the player is heading to the destination. The (x_p, y_p) is the current coordinate of the player, and (x_c, y_c) is the coordinate that the player clicked on the arena. By applying the arc tangent to find out the theta (θ) from the division result of absolute axis differences which is the angle of the player should be turned like a track. The θ is calculated until the player reaches the clicked coordinate.

$$\theta = tan^{-1}\left(\frac{|y_p - y_c|}{|x_p - x_c|}\right) \tag{1}$$

The game also involved the movement of all objects except for the stage boss, finite state machine (FSM) as shown in Fig. 5, will be applied in controlling the specific movements of all monsters to maintain the best game experience. Saini et al. (2011) stated FSM is used in a fighting game to what actions will be made according to the conditions of the player. Then, performing the actions to the AI player, which simulate the gameplay that like a human player in control. In the design, there are three states which are patrol, chase and escape to control the movements of monsters. Monsters are walking around in the arena in patrol state. They find out the best route then chase the

player in chase state. Then monster will leave in escape state. The escape is operated when they meet only.

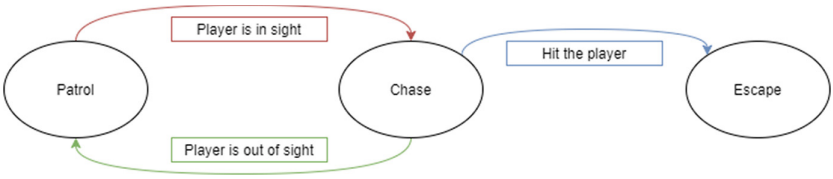

Fig. 5. States for monsters in finite state machine (FSM).

More in depth, according to the skeleton of the FSM is developed, the movement logic of each monster has been shown in Fig. 6. Monsters are generated then detect the distance to the player. If the distance is zero pixel (px) or less, which means they reached already, an arithmetic question is generated to the player. While the distance is in between 0 px and 210 px, the monster will chase the player according to the stamina of the player. If the stamina of player is more than 40%, the monster will move faster. And the monster will move slower in otherwise. While the monster is far away from the player, which is more than 210 px in the distance, the monster will generate a moving direction randomly and start to move. And the monster will get into another way if reached the arena boundary.

Moreover, the formula in (1) is also applicable to find out the turning angle of monsters. The formula in (2) is applied to find out the distance d of player and monster by the coordinates of the player with (x_p, y_p) and monster with (x_c, y_c).

$$d = \sqrt{(x_p - x_c)^2 + (y_p - y_c)^2} \tag{2}$$

3.3 Arithmetic Questions Design

The arithmetic questions design is the core part of the game. Since the target of the game is for nursery and junior primary students, and their calculation skills may not be substantial. The questions will be generated from the easiest to the hardest. That means questions will be generated an addition and subtraction with two terms in the first few stages. Then, according to the results, the complexity of the game will be increased or remain unchanged.

Relatively more straightforward questions will be generated in the beginner levels, like two terms with single digit addition (e.g. 4 + 3) and subtraction (e.g. 9-2). While the result of the scope is satisfied that the types of questions will be enhanced, like three terms arithmetic calculations (e.g. 1 + 2 + 3, 4 + 5–7). All answered questions would be recorded and analyzed. If any scope becomes weak, those types of questions are generated frequently as a remedial. However, the user may not know the type of questions that are duplicated as they are focusing on how to defeat the stage boss. For junior primary students, four terms with double digits in mixed arithmetic calculation

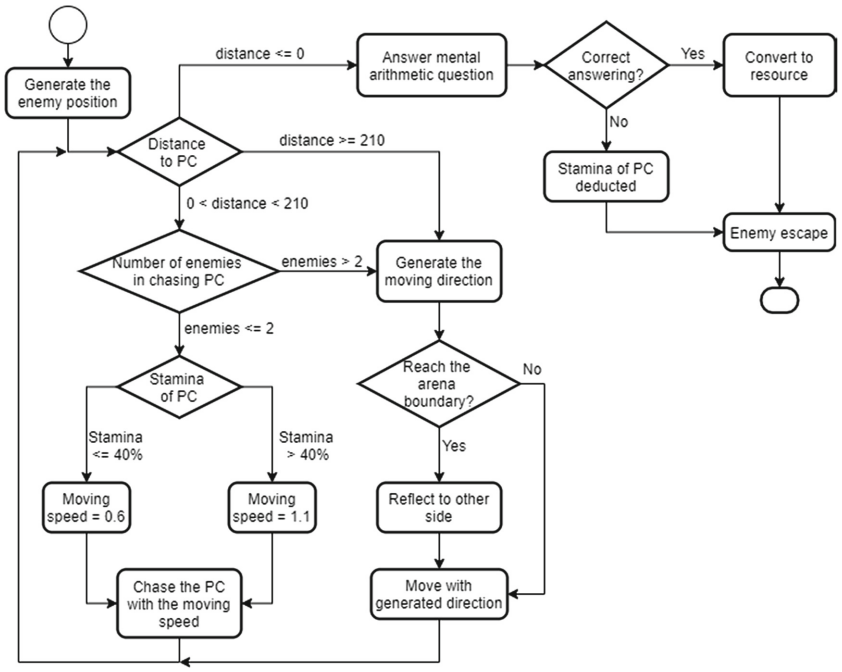

Fig. 6. The logic of monster movements.

will be the highest level in the game. For nursery students, the highest level is set to three terms with single digit mix calculated with addition and subtraction.

In details, Fig. 7 shows the logic in generating questions at a level. In each level, the maximum of possible questions will be concluded. According to the percentage of the questions generated, that means the player answered a quantity of questions, the model will start to search questions that answered incorrectly then mixed up with new questions then generate to the player by a "random factor". The random factor is a policy with a weighting value to consider generating a new question or regenerating an incorrect question from the result. The factor will tend to select incorrectly answered questions when the most of new questions are generated.

When 70% or more of new questions generated, the model will release questions according to the player's performance. If the correctness (performance) is 10% or lower, the model treated the player is weak in that scope. Remedial is needed then questions answered incorrectly that will be regenerated. When the performance is in between 10% and 80%, a new question or an incorrect question will be generated according to the random factor. Also, duplicated question cannot be selected continuously. If the performance is 80% or higher, a new question will be generated.

To make sure the stage boss can be defeated, the attack power of the player is related to the valid questions in each stage. For example, if 20 valid questions can be generated, the attack power of the player will be 5%. More valid questions can be generated in higher levels so that the attack power will be weakened. To avoid the player attends too many questions, the model will limit similar format of questions (e.g. 1 + 1 and

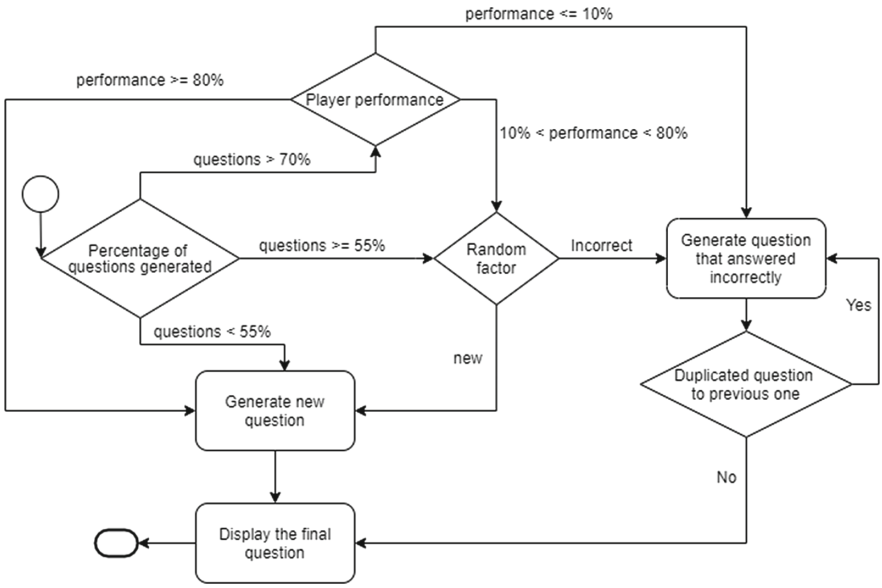

Fig. 7. The logic of question generation.

$1 + 2$) can be generated. Hence, the performance of the player in a stage can be more significantly performed.

4 Evaluation and Discussion

The application had been evaluated by thirteen preschoolers and junior primary children, accompanied by their parents. The evaluation was instantly followed by two post-experiment surveys, targeted for the children and their parents, respectively.

The game mode attracts all the children. They focus on how to collect the resources by applying their arithmetic ability, and how they can defeat the stage boss. Simple graphics can effectively attract their eyes to focus on the required targets.

However, the result in arithmetic improvement cannot be figured out at the moment because the evaluation period is too short. Pre- and post-tests with two sets of similar questions have been given to children to be completed before and after playing the game. Although the improvement has not been seen significantly, the reactions in doing calculation has been enhanced after completing the game.

From the feedback of the parents, the game could improve the arithmetic ability of children after playing for a period. Since the questions are at beginner level, some parents suggested the complexity can be increased and advanced arithmetic calculations can be added, for example, two digits arithmetic calculation, multiplication and division questions can be added. Furthermore, one of the parents suggested that the game can further be extended to other subjects, such as the Chinese language with word phrases matching and vocabulary spelling in the English language.

Parents feel comfortable about the game mode, they commented that it is well designed for kids as the game does not contain any violence or blood scenes. And it brings out a positive message that the evil will eventually be defeated by justice. The gameplay can effectively encourage the user to complete a task individually or work in a team with their parents. It has been frequently observed that when the children came up with a challenging question, they seek for the assistance from their parents.

The game is colorful to motivate the kids to play. Pixel-liked characters are set in high contrast that kids can see the targets clearly. Moreover, the game performed questions strategically, which focus on the weakest area of the users according to their previous performance in an individual run. This avoids the boredom brought by regular "drill and kill" methods but it can still consolidate the knowledge of the game player on weaker aspects.

In general, the application can satisfy the objectives to improve the mental arithmetic ability. Kids are motivated to communicate with their parents in learning through game playing. Hence, the parent-child relationship can be enhanced accordingly.

5 Conclusion

Learning environment for kids should be relaxing and enjoyable especially for the next generation kids. In this paper, a mobile game-based application has been developed to motivate the kids to learn mental arithmetic. The application promotes the use of game playing during learning. It can eventually enhance the users' mental arithmetic skills, problem-solving skills, and also the parent-child relationship by playing a funny and straightforward monster defeating game. The AI algorithm is set to release the mental arithmetic questions strategically to focus on the weakness of the user. As the related skill has been trained appropriately, users can experience this immersive way to learn mental arithmetic with fun effectively during game playing.

References

Baldeón, J., Puig, A., Rodríguez, I., Lopez, M., Grau, S., Escayola, M.: Gamification of elementary math learning: a game designer role-playing experience with kids. gEducation (GWC15) (2015)

Chu, E.: Ti Fa Zi Nu Shi Zui Wu Xiao De Guan Jiao Fang Fa. [Physical punishment of children is the most ineffective method of discipline]. Topick – Hong Kong Econimic Times (2018). https://topick.hket.com/article/1999446. Accessed 20 Sept 2020

Curran, K., George, C.: The future of web and mobile game development. Int. J. Cloud Comput. Serv. Sci. **1**(1), 25 (2012)

Curriculum Development Council: Basic Education Curriculum Guide. Cd.edb.gov.hk (2014). https://cd.edb.gov.hk/becg/english/index-2.html. Accessed 1 June 2020

Curriculum Development Council: Kindergarten Education Curriculum Guide. Education Bureau, Hong Kong (2017). https://www.edb.gov.hk/attachment/en/curriculum-development/major-level-of-edu/preprimary/ENG_KGECG_2017.pdf. Accessed 1 June 2020

Education Bureau: Free Quality Kindergarten Education. Education Bureau, Hong Kong (2016)

Education Bureau: Overview. Education Bureau, Hong Kong (2020). https://www.edb.gov.hk/en/student-parents/ncs-students/overview/index.html. Accessed 20 Sept 2020

Committee on Prevention of Student Suicides: Final Report November 2016. Government Printer, Hong Kong (2016)

Lee, L.-K., Chau, C.-P., Tsoi, K.-N., Yang, N.L., Wu, N.-I.: A mobile game for learning English vocabulary with augmented reality block builder. In: Cheung, S.K.S., Jiao, J., Lee, L.-K., Zhang, X., Li, K.C., Zhan, Z. (eds.) ICTE 2019. CCIS, vol. 1048, pp. 116–128. Springer, Singapore (2019). https://doi.org/10.1007/978-981-13-9895-7_11

Legislative Council committee: In Minutes of Legislative Council meeting 4 February 2019. Legislative Council: Chamber (2009). https://www.legco.gov.hk/yr08-09/english/counmtg/hansard/cm0204-translate-e.pdf. Accessed 20 Sept 2020

Legislative Council committee: In Minutes of Legislative Council meeting 18 March 2010. Legislative Council: Chamber (2010). https://www.legco.gov.hk/yr09-10/english/counmtg/hansard/cm0318-translate-e.pdf. Accessed 20 Sept 2020

Ngan, C.: Xue Ye Ya Li Chen Zhong Yi Nian Yu 10 Tong Zi Sha [More than 10 children committed suicide a year according to heavy academic pressure]. Wen Wei Po, June 2019. http://paper.wenweipo.com/2019/06/01/HK1906010026.htm. Accessed 20 Sept 2020

Pannu, A.: Artificial intelligence and its application in different areas. Artif. Intell. **4**(10), 79–84 (2015)

Pareto, L.: Mathematical literacy for everyone using arithmetic games. In: Proceedings of the 9th International Conference on Disability, Virtual Reality and Associated Technologies, vol. 9, pp. 87–96. University of Readings, Reading, September 2012

Roussou, M., Oliver, M., Slater, M.: The virtual playground: an educational virtual reality environment for evaluating interactivity and conceptual learning. Virtual R. **10**(3–4), 227–240 (2006)

Saini, S., Chung, P.W.H., Dawson, C.W.: Mimicking human strategies in fighting games using a data driven finite state machine. In: 2011 6th IEEE Joint International Information Technology and Artificial Intelligence Conference, vol. 2, pp. 389–393. IEEE, August 2011

Shields, J., Wells: Are VR headsets bad for your health? (n.d.). https://www.sciencefocus.com/future-technology/are-vr-headsets-bad-for-your-health/. Accessed 20 Sept 2020

Topick - Hong Kong Economic Times: Fu Mu Po 6 Sui Nan Tong Du Shu Du Bu Hao Da Dao Bu Neng Zi Ba Ling Ren Xin Tong [A heartbreaking issue with a 6-year-old boy was hit according to worst academic result by parents]. Topick – Hong Kong Econimic Times (2018). https://topick.hket.com/article/2101298. Accessed 20 Sept 2020

Zhang, D., Zhao, J.L., Zhou, L., Nunamaker Jr., J.F.: Can e-learning replace classroom learning? Commun. ACM **47**(5), 75–79 (2004)