Annex V

Quality Education Fund

Application with Grant Sought Exceeding $200,000

Part B: Project Proposal

Project Title 數學資通救地球 MATHero's Journey App	**Project Number** 2019/1095

Basic Information

Name of School / Organisation / ~~**Individual**~~

Department of Psychology), The Education University of Hong Kong

Co-I:

Department of Special Education and Counselling), The Education University of Hong Kong

Beneficiaries:
TWGHs Kwok Yat Wai College

(a) Sector: ☐Kindergarten ☐Primary ☑Secondary ☐Special
(Please tick the appropriate box(es))

(b) Students: ~ 400 (in number)* and Form 1-3 /Age 12-14 (class level/age)*

Students: ~ 10 (in number)* and Form 5 /Age 16-17 (class level/age)*

(c) Teachers: ~ 15 (in number)*

(d) Parents: ~ 800 (in number)*

(e) Participating Schools (excluding applicant school): 1 (in number and types)*

* *Please specify where appropriate*

Proposal

(I) Project Needs

(a) Please state the aims of the project in clear and concise terms and elaborate on how the proposed project could impact on school development.

As many students are not motivated to learn mathematics in Hong Kong (Michaelides et al., 2019), we propose using *gamification* theory (Burke, 2014) to create a new e-learning app *MATHero's Journey* to help motivate such students. This proposal applies innovative teaching and learning by adopt e-learning apps to provide greater diversity in teachers' teaching methods and enhance students' academic performance, thereby aligning with a key theme of the 2019 QEF on application of information technology. By storing information on the performances of different students and allowing choices of avatars, this proposal caters for learner diversity, and encourages students to use IT for self-directed learning, towards the goal of lifelong learning.

This project will develop a gamification platform to facilitate teaching and learning both inside and outside of the classroom. In this learning platform, teachers will work with EdUHK professionals and teachers to develop the MATHero app for various mathematics topics, which

will facilitate self-directed learning. The students will have new opportunities to challenge, confirm, or enhance their mathematics knowledge by solving mathematics problems.

After developing and testing the MATHero app in one pilot school, we will disseminate it to other schools, cultivate a learning community network, and eventually make it available to all students in Hong Kong to improve their mathematics. The application will provide an environment in which teachers can share, upload, and actualise their innovative ideas for teaching, with the support of EdUHK. In addition, the project will collect data on student performance from the apps platform to aid analysis of student outcomes.

The participating school has an admirable mission: whole-person education, developing potential, promoting bi-literacy and trilingualism. However, it faces the challenges of enhancing students' self-directed learning habits, their use of e-learning, and their appreciation of such benefits for their education. These problems are especially notable for learning mathematics. Traditional blackboard methods do not stimulate the interests of many students. Furthermore, these students often have poorer families, and few enjoy private tutoring, so they have few education resources outside of school. Some have family problems and little motivation to learn. Like their peers, many of these students are interested in the internet, smartphones, games and other apps. Thus, we will harness their interests by promoting their learning via the MATHero app in which they solve adventure problems with mathematics.

The aims of the project are to use the app technology to:

- Increase students' motivation to learn mathematics
- Increase student confidence to learn mathematics with technology and interactive elements
- Increase students' mathematics conceptual knowledge and skills
- Assess students' understandings of mathematics' topics
- Promote student use of education technology inside and outside the classroom, and
- Stimulate students' interest in personal formative assessment

The project will also:

- Equip teachers with professional, engaging technology in the classroom, and
- Provide them with an engaging homework option for students to enhance their learning of mathematics.

EdUHK educators will apply their expertise in mathematics education, computer science and interactive technology to help these teachers design and develop MATHero. Designers embed motivation engines into their online games via increasingly difficult challenges and frequent psychological rewards for success (*gamification*). Hence, such an online game for mathematics can provide a subtle, enjoyable way for students, especially less motivated ones, to learn mathematics and be a welcome addition to teachers' teaching toolkit.

(b)(i) What are the areas of the needs and priorities of the school?
(Please tick the appropriate box(es))

☑ Enhance learning and teaching to facilitate students' knowledge on subjects / learning areas / generic skills development
☐ Promote students' social and emotional development
☑ Enhance school management / leadership and teachers' professional development / wellness

(ii)Please give background information to justify the demonstrated needs as mentioned in (b)(i). (*Please tick the appropriate box(es))*

Needs of mathematics students for flexible learning with information technology assistance

For students who are not motivated to learn complex mathematics concepts, engaging them via gamification (Burke, 2014) of mathematics problem can motivate them. Furthermore, promoting flexible learning environments with information technology assistance can help motivate them to

do so. For students with unpleasant past experiences with mathematics in classrooms, a different environment without such unpleasant memories, such as a school playground, offers a fresh start (Singer & Salovey, 2010). Hence, we will use Q-R codes that enable students to play MATHero and solve applied mathematics problems outside classrooms, which in turn can help students appreciate the utility of mathematics in the world and motivate them to learn mathematics (Sawatzki & Sullivan, 2018).

Needs for tools to enhance teacher assessment and teaching

Also, beyond student homework, which demotivated students often do not complete, mathematics teachers have few tools or opportunities to assess their students and improve their teaching methods. Without access to suitable expertise or technological resources, many teachers cannot develop such tools. The MATHero app provides teachers with new ways to assess students' learning and new teaching possibilities. Teachers with shared interests in using MATHero can be brought together to develop professional learning communities across many schools.

☑ **School development plan:**

According to this school's implemented learning, teaching and development plans (School annual report and plan, 2018/19, 2019/20), they have enhanced their students' self-regulated learning and generic skills via e-learning, and are adopting existing educational apps for teacher-designed and tailor-made learning activities and after-class assignments. Our app will significantly add value to these activities.

☑ **Exam and Survey findings:**

S1-S3 students in this school showed poor mathematics learning outcomes, driving the need for substantial improvement (School annual report and plan, 2018/19, 2019/20).
Discussions with the mathematics teachers disclose a number of concerns. These include:

- Their students come from relatively poor backgrounds
- Their parents might find it difficult to give them educational support
- Few can afford private tutoring
- Poor performance in mathematics results in demotivation and loss of confidence
- Existing resources are not sufficient to address the issues
- Class sizes of ~30 students hinder teachers' efforts to give special attention to students with weaker mathematics.

Teachers would like to find ways to enhance students' learning outcomes, and they believe that app technology can provide a valuable learning aid that their students would welcome (School development plan, 2017-2020). Specifically, gamification of mathematics learning via an app helps motivate students to use it and enhance their mathematics understanding, as shown in the research studies reviewed below.

☑ **Literature review summary:**

According to the National Council of Teachers Mathematics, (2000), "Technology is essential in teaching and learning mathematics; it influences the mathematics that is taught and enhances students' learning" (p. 24). Specifically, online and mobile learning applications can (a) motivate students to learn and (b) make mathematics more enjoyable and interactive (Drigas & Pappas, 2015; Jong et al., 2013; Wang & Towey, 2013).

<u>Gamification of innovative learning for students</u>

Today's learners are digital natives who grew up with digital technologies (Helsper & Eynon, 2010). As students often enjoy playing online games in their free time, they are likely to enjoy comparable learning games via gamification (Lee et al., 2011).

Gamification is defined as the use of game mechanics to engage and motivate people across activities to reach their goals (Burke, 2014).

Students enjoy learning by playing games. A gamified environment provides a pleasant and relaxing experience, which can stimulate and encourage students to learn independently (Jong, et al., 2013). Students showed increasing enthusiasm and motivation on learning activities with digital game elements, which in turn, contributed to moderately superior learning outcomes (Wang & Towey 2013; Kwan et al., 2015).

In addition to learning motivation and learning performance, Huang et al. (2014) highlighted the positive effects of correcting learning worries through game elements on mathematics. Jong et al. (2013) showed that game elements are extremely beneficial to students with poor academic performance, while Yi & Chu (2017) and Kiili et al., (2015) show that gamification promotes self-study outside the classroom. To meet the learning needs and interests of 21st century students, appropriate use of game activities should be incorporated into existing courses (Uzun et al., 2013).

Game-based learning to enhance motivation

Game-based learning combines autonomy, goal structure, and feedback to motivate students to learn enjoyably. First, students have the freedom (*autonomy*) to choose their actions toward achieving an overall goal (Ryan & Deci, 2017). Second, this overall goal is subdivided into many smaller subgoals (*goal structure*), such that achieving earlier goals aids attainment of later goals (Burke, 2014). Also, students receive an immediate evaluation of their success (or failure, *immediate feedback*), sometimes with information that can improve their subsequent likelihood of success (e.g., tips, Yan & Brown, 2017). These game elements encourage students to persist through failure to eventually succeed and to learn (Hanus & Fox, 2015).

Such use of game elements can improve intrinsic motivation by satisfying users' innate psychological needs for performance gains and associated with improved psychological well-being, enhanced creativity, and learning outcomes (Hamari et al., 2014; Ryan & Deci, 2000). Gamified systems that fulfill these fundamental psychological needs increase students' motivation and drive efficient self-determined learning (Burke, 2014).

Gamification applies these motivation and game principles to traditional, non-game situations, capitalizing on student desire to be an active participant with freedom and autonomy (Khaleel et al., 2016). Khaleel et al. (2016) suggest using game elements with three objectives: increase the level of entertainment and fun, motivate learners to challenge one another, and improve gaming and learning skills. They also concluded that applying engaging and effective teaching and learning techniques are essential and that gamification is most valuable for difficult subjects (e.g., mathematics for many students). Such motivation via gamification is especially valuable for students who are not motivated by traditional classroom teaching (Stacey, 2016), and a well-designed digital game can improve students' learning outcomes (Kwan et al., 2015).

Many studies showed that gamification benefits secondary school students by uplifting motivation, increasing self-learning time, enhancing learning outcomes, and ultimately cultivating a proactive learning atmosphere (Kwan et al., 2015; Wang & Towey 2013; Xu & Ke 2016; Serpe, 2017; Toda et al., 2014).

☑ **Assessments on students' performance:**
The school's mathematics results show that many students have difficulty learning mathematics (School report, 2018/19). As shown in the assessment and self-evaluation of teachers in previous school years, they are concerned about their students' mathematics learning outcomes and believe that they need to improve their mathematics teaching. The teacher concerns also align with the school development plan to promote mathematics learning.

See details on evaluating the effectiveness of this project in Section III.

☑ **Relevant experiences:**
The project team comprises experts in mathematics teaching, assessment, and computing skills, with substantial experience teaching via technology, e-learning, and interactive apps. The school's development plan (2017-2020) specifies their (a) commitment to e-teaching and (b) uses of it in their classrooms.

The Principal Investigator (PI) has taught mathematics and trained teachers for over 30 years. The PI taught mathematics at all levels—primary, secondary and tertiary—and researched mathematics teaching extensively. Currently, a senior lecturer in the Department of Psychology of EdUHK, the PI teaches psychology and mathematics learning (both theory and practice), with specific expertise on junior Form S1-S3 secondary students who often grapple with abstract complex concepts and discover mathematics relations. The PI has published several articles including, 'Investigating the Reason for Low Achievement amongst Early Learners of Mathematics' (Kwan, 2018) and 'The Interplay between Conceptual and Procedural Knowledge in the Learning of Mathematics' (Kwan, 2018), etc. The PI has developed apps to improve students' learning experience. Her recent apps include *E-portfolio*, which promotes students' skills of self-reflection, and *Teaching Experience*, which enhances student teachers' skills, strategies and confidence to teach in schools.

Chair Professor of Analytics and Diversity Ming Ming CHIU at EdUHK is a Co-investigator with a Computer Science BS (Columbia); Interactive Technology MEd (Harvard); and Mathematics Education PhD (UC-Berkeley). He has created algebra computer software and published in the best mathematics education journals (JRME, ESM). He is also Director of the award-winning Assessment Research Center, with 36 academic partners within 20 universities in 9 countries across 4 continents. Funded by 54 grants for HK$82 million, Prof. Chiu has 219 research publications (134 journal articles, 8,000+ citations) and 165 news articles in 21 countries. He will lead the assessment and support all aspects of the project.

c. Please elaborate on the innovative ideas or new practices to enhance, adapt, complement and/or supplement the existing practices that will facilitate the development of the school to address the needs specific to its own context.

This project will immerse students in playing an adventure game app MATHero that requires solving adventure problems with mathematics. MATHero is a mobile app that students can access on their smartphones or tablets. First, they must walk around their school, point their phone camera at posters with Q-R codes and scan them to reveal adventure episodes. Each adventure episode requires completing a task (e.g., capturing a monster) via solving a mathematics problem (e.g., computing the rope needed to make a net to capture the monster). Hence, the app also shows the applicability of mathematics to the physical world. Within this storyline, students can design their character and avatar. As they complete more adventures, they gain experience points, and their avatar becomes more powerful.

After we complete the design and development of MATHero, school teachers can easily control and modify the App by:

- Enabling specific students to play the game
- Input questions
- Select numbers, types and difficulties of questions (e.g., Level I has 10 easy geometry questions about polygon area).
- Setting adventure locations

(II) Project Feasibility

(a) Please describe the design of the project, including:

(i) Approach/Design/Activity :

App Innovative design with gamification elements

The project adopts gamification (Burke, 2014) via apps technology to create MATHero to motivate

S1-S3 students to solve mathematics problems inside and outside the classroom.

In our proposed single-player *MATHero's Journey*, a student chooses an avatar who faces many challenge along an adventure journey to defeat a monster king and save a kingdom. The *autonomy* to choose an avatar and the simple, clear *goal* motivates a student to take on this *identity* (Ryan & Deci, 2017) and become a hero. This overall goal consists of many smaller challenges (Burke, 2014). Each challenge is a problem that must be solved by applying high school-level mathematics. By succeeding on easy early challenges, like finding the correct geometric key to open a cage, the student becomes more *confident* (Hanus & Fox, 2015). Successive challenges, like killing deadlier monsters, are harder but have *increasing value*, motivating students to continue playing this game (Burke, 2014). If a student initially fails to kill a monster, she receives *immediate feedback* to help her learn and succeed (Yan & Brown, 2017) as she tries again and again, with different strategies, at her own pace, on her own time, under her *control* (Ryan & Deci, 2000). Eventually, she kills it, *valuing* her success more because of earlier failures, and feels excited about the next challenge (Hanus & Fox, 2015). If she persists, she eventually defeats the monster king and saves the kingdom. Together, these design elements can drive students to spend their free time enjoying them and learning mathematics (Burke, 2014).

The project uses a crossover, controlled experiment to test the effectiveness of MATHero at improving student mathematics problem solving.

This mathematics problem solving app provides corrective instruction, and gives students multiple opportunities to improve and succeed. This formative assessment provides feedback that effectively helps students learn (see meta-analysis by Hattie, 2009).

The MATHero app assesses the students' learning ability. Each app's question offers four choices, in which wrong answers capture common student mistakes. When students are not sure how to solve the problem, they can pay for a hint (which costs experience points) to help them. After solving a problem to complete an adventure episode (e.g., reading map coordinates correctly to find a sword), they earn experience points and proceed to the next adventure. Students with few or no learning errors can receive enrichment activities to help broaden and expand their learning (See examples in Appendix II).

Questions types incorporated in the mobile application

We will create a database of 500 questions at different levels of difficulty, and teachers can add their own questions. Teachers can select questions by topic and by difficulty according to students' needs (e.g., 5 difficult ones on angles, 10 easy ones on area, etc.).

In accordance with the results from the mathematics teachers' preference survey and the majority of students' needs, the app will include all S1 - S3 mathematics topics. According to the school syllabus and survey from teachers, 10 main topics have been chosen (Appendix I). Each topic will have 50 questions. The school's teachers will work with EdUHK professionals to develop learning materials for various mathematics topics and design the questions based on their current homework, quiz and test questions.

Teachers can integrate these problems into their lessons and offer a blended learning experience for their students. Students can access the materials at any time to fulfill class requirements or for self-study.

Learning materials package

- Teacher online website resources with 500 multiple choice questions, and videos explaining the use of the apps, and other supplementary materials that reinforce course content.
- Developed MATHero App
- User Manual in electronic format for students and teacher with video guide on how to use the App.

Difficulty level of questions types

Effective practice to enhance learning requires a rich pool of problems of different levels of difficulty, especially in mathematics, to create the appropriate goal structure to motivate students via flow (Hanus & Fox, 2015). Students experience *flow* when a challenges is at the maximum extent of their individual skills, competences and knowledge (Csikszentmihalyi, 2020). Our design will support for dynamic generation of problems from different difficulty level (Easy, Medium or Hard) for students to master students' S1-S3 mathematics topics.

Reward element- Badges/winning records

To motivate and foster independent learning, MATHero has several gamification elements. Learning activities are provided with immediate feedback including detailed progress information and rewards (experience points, badges, and virtual currency). The platform enables teachers to tailor the gamification features. The gamification platform includes the choice of the game elements to be used in the specific topics along with specification of gaming rules for them. The system currently supports the following game elements: experience points, levels, progress bar, virtual currency, badges, learner dashboard, avatars, and immediate feedback. The gaming rules define the conditions upon which certain game elements are applied (e.g. a specific badge is awarded).

When students answer questions correctly, they not only gain mathematics skills but also earn experience points. These experience points can be used to buy hints, answer questions worth more experience points, and advance to superior avatars. After advancing to a superior avatar, they face harder adventure challenges, which in turn require solving harder mathematics problems. Greater success yields higher levels (e.g., stronger monsters) and greater mathematics challenges. A leaderboard publicizes competitive goals and gives social-psychological rewards for successes. (See the workflow of a gamified learning process of the app in Appendix III).

In this project, teachers help create an innovative, formative assessment that capitalizes on student interest in playing computer games. Students can play the MATHero app in their free time, allowing them to revise and deepen their mathematics knowledge. Meanwhile, teachers will benefit from teaching students who practice much more of their mathematics.

Q-R codes/markers

Many studies show the advantages of using gamification in education as stated in Part I b (ii) (Lee et al., 2011, Khaleel et al., 2016, Stacey, 2016). Likewise, promoting hands-on use of technology in the classroom is in line with Hong Kong Schools' development philosophy. The students use what they have learned to win the MATHero game to deepen their mathematics understanding. The app also helps the school identify and address the specific needs of diverse students (both mathematically gifted students and students with mathematics learning difficulties).

This interactive app immerses students into a hero's journey. To free students from possibly unpleasant memories of mathematics failures in their classroom, they must do a physical search (within the school's physical environment) for treasures (with Q-R codes/markers) and solve problems with mathematics (e.g., to capture monsters). These problems include superficial information and in-depth information to give students opportunities to use their metacognition to evaluate the relevance of each piece of information to solving the problem (Chiu, 2017). As the app records student choices, the teacher can assess students' app uses and mathematics problem solving.

As the app accesses Q-R codes, it can be used anywhere (in the classroom, field trip, etc.); the teacher simply brings the Q-R codes.

The app also stores mathematics information. For instance, a teacher who discussing a *right triangle* can ask her students to click on the app and search for "right triangle." Such discussions

undergird students' problem solving during their MATHero adventures.

QR code features such as visual elements, attractiveness, and direct routing can improve learning. In a study by McCabe and Tedesco (2012), QR codes were used via smart phones for direct connection with the subjects within the scope of the course of mathematics. Also, 83% of the students reported less stress when they studied for the lessons and could instantly access the necessary information with the help of QR codes (McCabe & Tedesco, 2012). Indeed, students typically report that using QR codes are easy and that they enjoy using them (Law & So, 2010).

Feedback given by scaffolding students in the learning process

Effective teaching uses a range of scaffolding practices that support the students in their learning process (Anghileri, 2006). After teachers define mathematics problems for testing students' knowledge and skills, they organize them in sequence from easy to hard (goal structure, Burke, 2014). Completing harder problems gives students high rewards (e.g. more experience points that can be used for hints on later problems). Following scaffolding principles, each successive hint on a problem is progressively more helpful (Rittle-Johnson et al., 2017).

Using adventure as an overarching design

We will incorporate elements of adventure storytelling into MATHero.

Students select a hero character and navigate within a designed story with characters, a plot, setting, conflict and resolution (via solving mathematics problems, such as finding locations on a map / coordinate plane, see Appendix II, Example 2). Practicing solving mathematics problems within a coherent story entails students creating more links/paths to mathematics concepts in their brains, thereby enhancing their memory as well as their enjoyment (Gluck et al., 2016).

Problem-solving is the core learning element of mathematics education

This Mathematics project motivates students to develop mathematical problem solving skills and helps them do so via their interest in adventures beyond academic problems in school. Solving diverse problems across contexts helps students to consider, discuss, and apply their mathematics to new areas (*transferability*).

Facilitate students' learning of different levels

These mathematics questions not only motivate students to learn new mathematics ideas/skills but also help them learn them, integrate their existing knowledge, and facilitate their application to more situations, especially novel ones. For students who do not know a mathematical concept (e.g., two *similar* triangles have the same set of three angles [e.g., 30^o, 60^o and 90^o] and corresponding proportional sides) can use the information in the problem to learn it. For example, an adventure problem requires chopping down a tree that is tall enough to use to cross a ravine; it requires using my height, my shadow, and a tree's shadow to determine its height. The ravine problem not only motivates the importance of similar triangles but also provides rich information about the person's height, person's shadow, and tree's shadow. This information helps a student connect the corresponding (similar) parts of a person, namely height and shadow (2 legs of a triangle), to those of the tree (height and shadow).

Furthermore, the app scaffolds student learning with gradually escalating hints. The initial hint is broad (e.g., consider your shadow and the tree's shadow), while a later hint is more specific (e.g., tree's height and shadow are proportional to your height and shadow.) This scaffolding provides less help for more knowledgeable students and more help for less knowledgeable students.

The mathematics questions across diverse contexts expose students to different possible

applications of mathematics concepts and skills, which helps them integrate and consolidate their mathematics knowledge, expand their application range to the broader world and aid creative applications in novel contexts.

(ii) Key Implementation Details

Project period: 10/2021 to 5/2023

Month / Year	**Content / Activity / Event**
10/2021-11/2021	- Recruit apps designer, draft work plan and procure equipment and materials. - Setup server for development of the game.
12/2021-8/2022	App development - Design learning activities within the app - Create design specification for the mobile game (including data flow and process, data structure, storyboard, interface, and game logic) - Design game content - Design graphic and sound effects for the game - Prepare instruction manual for student activities - Develop learning notes for all problems in the app
9/2022	Training session on relevant skills of the apps for teachers and student leaders. -Training session for a maximum of 15 Maths and ICT teachers from the service provider and project team. (The duration of the training session is 2 hours) -The training session will be conducted in the school computer room with Internet support to demonstrate the use of the app and data collection. An administrator user manual will be provided for reference.
10/2022-3/2023	Prototype testing and refinement - Conduct the learning activities in the app for all Form 1-3 classes - Evaluate student engagement, ease of use of the app, use frequency, use intensity, and mathematics performance across time - Refine mathematics problems, learning notes, and app
4/2023-5/2023	Review and report - Evaluate and review project effectiveness. - Final report upon conclusion of the project - Organise sharing session within the school to showcase students' learning outcomes and share teaching hints - Make recommendation and compile the project report

(b) Please explain the extent of teachers' and/or principal's involvement and their roles in the project.

(i) Number of teachers involved and degree of input (time, types, etc.):

The project team consists of 19 members: Principal Investigator, Co-Investigator, Principal, Assistant Principal, 5 computer teachers, and 10 mathematics teachers. 15 teachers will be actively involved in assessing students' use of and success with the app, monitoring them, and evaluating the results.

(ii) Roles of teachers in the project:

(*Please tick the appropriate box(es)*)

☑ Leader ☑ Co-ordinator

☐ Developer ☑ Service recipient

☐ Others (please specify) _____

For EdUHK professionals-

Role of Principal Investigator and Co-Investigator

- Overall in-charge
- Advise the developer on content (mathematics word problems, correct answers, frequent wrong answers).
- Networking and liaison with all external stakeholders.
- Evaluate project effectiveness by reviewing the survey results and teachers' assessments of their students' learning outcomes.
- Work with teachers to formulate the framework and content of the project and set up a working group.
- Meet with group members regularly and monitor the effectiveness of the project.
- Preparation of Project Reports, Finance, Presentations and Publishing.

For Teachers

Role of 5 Computer teachers:

The school's panel leader for computer studies has been actively involved throughout all stages from the original concept to the design. He will be in charge of the roll-out, beta-testing, training, and implementation. Specifically, he will:

- Formulate details of the project activities' arrangements with working group members.
- Meet with collaborating partners to plan and implement the project activities.
- Report regularly to the principal on the progress of the activities.
- Review the effectiveness of the project activities.

Role of 10 mathematics teachers:

- Design the mathematics questions according to the needs of their students.
- Enlist parents as parent-student co-learners in the project.
- Implement the project activities according to the project schedule and observe the performance of students' learning.
- Review the effectiveness of the project and follow up.
- Participate in regular meetings with collaborating partners to review the effectiveness of the project activities.

Role of the Principal and Assistant Principal:

- Work with teachers to formulate the project framework and content, and set up a working group.
- Meet with group members regularly to monitor the effectiveness of the project.
- Evaluate project effectiveness via reviewing the results and teachers' assessments of their students' mathematics learning outcomes

For Students

This easy-to-use app is targeted at S1-S3 students. It will help students apply and consolidate their primary school learning.

A group of 10 students from higher forms (student leaders) will be taught how to use the app, and they can enhance their communication skills by showing S1-S3 students how to use it. They will also be available to help any student who is having difficulty with the app. As the app provides extensive visual and content information, students can discuss the problems together (or with student leaders) and collaborate on a solution. All participants can benefit: they can gain more confidence, more enjoyment in the learning of math, and increased social skills.

Parent Involvement

The app will be explained to parents. Their support can be very valuable because most students will use the app on their own smartphone or a family member's smartphone, often at home. (Although the school has some facilities, these will be reserved for students who do not have a smartphone.)

Use of Devices
'Bring your own device' policy is being implemented in 2019/2020, and students are asked to bring their own devices to school. The school lends devices to those who do not have one. The school will provide training for parents so that students without their own device can use a parent's device at home.

Mini-game mode for classroom instruction, teacher training and professional development
Aside from students' *adventure* mode outside the classroom, MATHero can also pose a specific set of questions (*mini-game* mode) for classroom lessons or professional development (PD). Teachers can have students work on one or more MATHero problems (with or without the possible answers) during class, compare ways to solve them, check for common errors, and create (and solve) different related problems. Further interactivity includes using the questions in the App alongside Kahoot or Quizizz. Also, teachers can also select a set of mini-game questions to assess students' understanding of a specific topic (as a quiz or part of a test).

Mini-game mode also supports PD of teachers by having them role-play students and/or teachers using MATHero during a lesson. Such teachers can appreciate students' perspectives regarding the difficulty of understanding and applying mathematics concepts to solve problems within an immersive environment. Furthermore, such PD experiences help teachers recognize such app technology's strengths and limitations, anticipate and diagnose student difficulties, and design suitable responses to aid student learning, thereby developing teaching tools to help students appreciate and understand mathematics. By expanding the scope of students' mathematics learning inside and outside the classroom, teachers can also expand their own thinking and develop more creative teaching and learning methods.

The app will provide an environment in which mathematics teachers can actualise their innovative ideas for teaching, with the support of EdUHK. In addition, the project will enable EdUHK to generate data on student learning from the app, for the analysis of student learning and facilitate teacher in serving and assessing their students.

(c) Please provide the budget of the project and justify the major items involved.

Grant Sought: HK$**__$ 571,900 _ **(to the closest hundreds)

Budget Item	**Expenditure Detail (Including the breakdown for the budget items)**		**Justifications**
	Item	**Amount ($)**	
i) Staff Cost ($101,220)	1) Part-time Research Assistants (RA) $88 x 550 hours x 1.05	$50,820	RA and SH will be hired in the implementation and assisting of the project respectively. For RA Qualification and experience: The entry requirement for this post is the attainment of at least Level 2 or equivalent in five subjects including Chinese Language, English Language and Mathematics in HKDSE; or Grade E (Level 2) or above in five subjects including Chinese, English and Mathematics in HKCEE or equivalent. 1) To manage the project development, be accountable

			to the project team members; 2) To coordinate with the project school for developing materials and training workshop; 3) To assist the team in establishing and updating the app platform; 4) To assist in designing the app content and activities; 5) To analyse the project data, arrange regular team meetings and draft the reports; 6) To liaise with external IT consultants and arrange procurement; 7) To assist in the production of deliverables; 8) To assist in monitoring the project budget, overseeing work quality and preparing project reports.
	2) Part-time Student Helpers (SH) $60 x 800 hours x 1.05	$50,400	<u>For SH</u> Qualification and experience: Students in the Education University of Hong Kong. 1) To provide support to the project team in documentary analyses and data processing; 2) To assist in developing learning materials; 3) To assist in the production of training materials; 4) To provide clerical support.
ii) Service Cost ($360,000)	App and Web backend development Graphic design Server hosting cost for sustaining the developed App with maintenance	$ 217,200 $ 120,800 $22,000	A outsource app developer will be hired to develop a mobile application. Qualification and experience: Service provider shall possess a diploma or above in computer-related field. Experienced in setup an App, multimedia design, websites and related fields. Server will support a maximum 1,000 of concurrent users, and the server hosting cost for sustaining the application for 2 years. 1) To create interactive wireframes and design the learning and teaching activities and assessment

			strategies in the development of the app. 2) To develop the programming, the codes and the database design of the app. 3) The server hosts the game and records all learning activities. 4) For Character Design and Illustration on 500 mathematics questions.
iii) General Expenses ($110,680)	1) Photocopying and printing	$20,000	1) Production of training materials 2) Production of learning and relevant materials 3) Production of User menu
	2) Transportation	$5,000	1) Travelling costs 2) Materials delivery 3) Conducting training workshops 4) Conducting evaluation activities
	3) Miscellaneous	$6,097	1) Reference books and materials required for producing learning materials 2) Stationaries
	4) Audit fee	$5,000	An auditing fee is required for the project.
	5) Overhead cost charge	$74,583	Cover the administrative overhead charged by the University
Total Grant Sought ($):		**$571,900**	

The proposed application is a newly developed one. The copyrights of the deliverables/materials developed should be vested with the QEF. Any reproduction, adaption, distribution, dissemination or making available of the deliverables to the public for commercial purposes by the service provider is strictly prohibited.

(III) Expected Project Outcomes

(i) Please describe how to evaluate the effectiveness of the project.
(*Please tick the appropriate box(es)*)

Project evaluation includes assessment of student learning outcomes and of MATHero app uses.

Students' perception survey

Surveys of students will enable them to report on their experiences, perceptions, motivations and future plans for using MATHero. To ensure a valid and reliable result on survey findings, a power analysis shows that for statistical power of .80, $\alpha = .05$, a minimal effect size of 0.2, the minimum sample size required is 193 students. Hence, we will have ~200 students to complete this survey. To reduce survey measurement error, we use multiple questions for each construct to create a precise index via *factor analyses* (Joreskog & Sorbom, 2018). To properly model multiple

outcomes and simultaneous indirect mediation relations among these constructs, we use a *structural equation model* (Joreskog & Sorbom, 2018).

Crossover experiment

Based on the above power analysis, we will have ~200 students participate in crossover randomized controlled experiment. In the first phase, all participants receive a standard mathematics pre-test. Then, the students in one class are the experimental group, and students in another one are the control group. The experimental group receives MATHero to use. The control group of students receives no intervention. Then, all participants receive a post-test that has some pre-test questions (*anchor items* to calibrate both tests on the same scale to facilitate comparisons, *item response theory*, Embretson & Reise, 2013). In the second phase, all participants receive a different pre-test. Then, the control group receives MATHero and the experimental group no longer can use MATHero (deactivated) in this crossover part. Lastly, all participants receive a post-test with anchor items from the second pre-test (Embretson & Reise, 2013). To determine the effectiveness of this gamification approach via MATHero, we use *difference-in-differences analysis* (Bertrand et al., 2004)

Observation of lessons

We also compare ten typical mathematics lessons with ten gamified mathematics lessons by ten teachers in their ten classes (~350 students, ~35 students per class) with *counter-balanced ordering*. Two research assistants with teaching experience will each observe each lesson and record students' and teachers' behaviors on 20 observation reports (one per lesson). They will observe students' learning when the app technology is implemented, focusing on whether the students' mathematics problem solving behaviors differ across lessons by the same teacher, including the extent of use (how often and for how long), degree of success, uses of hints, engagement, and enthusiasm. To test for differences across these pairs of lessons, we determine *inter-rater reliability* with Krippendorf's α (2012) and use a *difference-in-differences multilevel structural equation model with residual centering* (Bertrand et al., 2004; Crandall et al., 2012; Joreskog & Sorbom, 2018).

(For the detailed success criteria and evaluation methods, please refer to Appendix IV.)

(ii) Please state the project deliverables or outcomes.
(*Please tick the appropriate box(es)*)

☑ Learning and teaching materials
☐ Resource package
☐ DVD
☑ Others (please specify) Apps development

(IV) Targets and Expected number of Beneficiaries

Targets

All future S1-S3 students might benefit from this proposed project (Education Bureau, 2019). In the trial run, ~ 400 students from the participating school will be invited to participate in different learning tasks offered in the MATHero app.

Expected number of beneficiaries in secondary schools

All future S1-S3 students might benefit from this app. If the methodology is proven to be effective, it will be shared with the Tung Wah group of schools and the general public. The game will be made available on common mobile platforms such as Google Play.

Sustainability of the project

Extend to more Mathematics topics

This is an app specifically designed for enhancement, enlargement and sustainability. If the methodology is proven to be effective, it can be extended to other Mathematics topics. Similar game content supported by specific assessments can be designed for students.

Extend to other subjects

After showing its effectiveness for mathematics learning, it can be modified for other subjects. We believe that, once teachers recognize the versatility of the app, they will be eager to expand it to other parts of their curriculum.

Available for students and teachers

Once the proposed digital game has been created, we plan to make it available for students and teachers to download.

Our project team will refine the gamification approach by acquiring and consolidating feedback from stakeholders.

(V) Dissemination

Our project team will conduct a sharing session to introduce the gamification approach and share our experience with other secondary schools. We will gladly give guidance about the setup and application to interested secondary schools.

The school is part of a larger group of Tung Wah, so the app can be made available to all of its members. It can be used by any school, anywhere in the future. To expand the app to other areas would require further help from the app developer and subject experts. This will require further funds, perhaps by way of grants, or by investment from the Tung Wah group (17 kindergartens, 13 primary schools, 18 secondary schools). Initial enquires of the school suggest that, if the app is successful, they would be prepared to invest in its further development. Latest news of this project will be delivered through the school website.

(VI) Asset Usage Plan (Not applicable)

(VII) Report Submission Schedule

The project team commits to submit proper reports in strict accordance with the schedule below.

Project Management (Should be submitted via the "Electronic Project Management System" (EPMS))		**Financial Management** (Hard copy together with supporting documents should be submitted to the QEF Secretariat by mail or in person)	
Type of report and reporting period	**Report due on**	**Type of report and reporting period**	**Report due on**
Progress Report 01/10/2021 - 31/03/2022	30/04/2022	Interim Financial Report 01/10/2021 - 31/03/2022	30/04/2022
Progress Report 01/04/2022 - 30/09/2022	31/10/2022	Interim Financial Report 01/04/2022 - 30/09/2022	31/10/2022
Progress Report 01/10/2022 - 31/03/2023	30/04/2023	Interim Financial Report 01/10/2022 - 31/03/2023	30/04/2023
Final Report 01/10/2021 - 31/05/2023	31/08/2023	Final Financial Report 01/04/2023 - 31/05/2023	31/08/2023

References

Anghileri J. (2006). Scaffolding practices that enhance mathematics learning. *Journal of Mathematics Teacher Education.* 9(1):33-52.

Bertrand, M., Duflo, E., & Mullainathan, S. (2004). How much should we trust differences-in-differences estimates? *Quarterly Journal of Economics, 119*(1), 249-275.

Burke, B. (2014). *Gamify: How gamification motivates people to do extraordinary things*. Brookline – MA: Bibliomotion.

Chiu, M. M. (2017). Self-beliefs, metacognition and mathematics achievement: A comparison of US and East-Asian students. In Margaret Williams's (Ed.) *Self-Concept: Perceptions, Cultural Influences and Gender Differences* (pp. 35-56). Hauppauge, NY. Nova Science.

Crandall, C. S., Preacher, K. J., Bovaird, J. A., Card, N. A., & Little, T. D. (2012). Structural equation modeling of mediation and moderation with contextual factors. In A. Bovaird & N. A. Card (Eds.) *Modeling contextual effects in longitudinal studies* (pp. 211-234). New York: Routledge.

Csikszentmihalyi, M. (2020). *Finding flow*. Hachette UK.

Drigas, A. & Pappas, M. (2015). A Review of Mobile Learning Applications for Mathematics. *International Journal of Interactive Mobile Technologies (iJIM). 9*. 18-23. 10.3991/ijim.v9i3.4420.

Education Bureau (2019). Student Enrolment Statistics, 2019/20 (Kindergarten, Primary and Secondary Levels). School Education Statistics Section, Education Bureau.

Embretson, S. E., & Reise, S. P. (2013). *Item response theory*. London: Psychology Press.

Gluck, M. A., Mercado, E., & Myers, C. E. (2016). *Learning and memory: From brain to behavior*. Worth Publishers.

Hamari, J., Koivisto, J., & Sarsa, H. (2014). Does gamification work? - literature review of empirical studies on gamification. In Proceedings of the 47th Hawaii International Conference on System Sciences.

Hanus, M. D., & Fox, J. (2015). Assessing the effects of gamification in the classroom: a longitudinal study on intrinsic motivation, social comparison, satisfaction, effort, and academic performance. *Computers & Education*, 80, 152-161.

Hattie, J. (2009). *Visible learning: A synthesis of over 800 meta-analyses relating to achievement.* London: Routledge.

Helsper, E. J., & Eynon, R. (2010). Digital natives. *British educational research journal*, *36*(3), 503-520.

Huang, Y. M., Huang, S. H., & Wu, T. T. (2014). Embedding diagnostic mechanisms in a digital game for learning mathematics. *Educational Technology Research and Development*, 62(2), 187-207.

Jong, M. S., Lee, J. H., & Shang, J. (2013). Educational use of computer games: where we are, and what's next. In Reshaping Learning (pp. 299-320). Springer Berlin Heidelberg

Joreskog, K., & Sorbom, D. (2018). *LISREL 10.1*. New York: Scientific Software International.

Khaleel, F. L., Ashaari N.S., Tengku Wook, T. S. M., & Ismail, A. (2016). Gamification elements for learning applications. *International Journal on Advanced Science, Engineering and Information Technology*, *6*(6), 868-874.

Kwan, A., & et al. (2015). Making Smart Choices: A Serious Game for Sex Education for Young Adolescents. *International Journal of Game-Based Learning (IJGBL),* 5(1), pp.18-30.

Kiili, K. J. M., Devlin, K., & Multisilta, J. (2015). Editorial: is game-based math learning finally coming of age. Intl. J. Serious Games, 2(4).

Law, C. & So, S. (2010). QR codes in education. *Journal of Educational Technology Development and Exchange*, 3(1), 85-100.

Lee, Joey & Hammer, Jessica. (2011). Gamification in Education: What, How, Why Bother? *Academic Exchange Quarterly. 15*. 1-5.

McCabe, M. Tedesco, S. (2012). Using QR Codes and Mobile Devices to Foster a Learning Environment for Mathematics Education. *International Journal of Technology.*

Michaelides, M. P., Brown, G. T., Eklöf, H., & Papanastasiou, E. C. (2019). Cluster Analysis Results for TIMSS 2015 Mathematics Motivation by Grade and Jurisdiction. In *Motivational Profiles in TIMSS Mathematics* (pp. 41-71). Springer, Cham.

National Council of Teachers of Mathematics (NCTM). (2000). *The Technology Principle: Principles and Standards for School Mathematics.* Reston, VA: NCTM.

Rittle-Johnson, B., Loehr, A. M., & Durkin, K. (2017). Promoting self-explanation to improve mathematics learning: A meta-analysis and instructional design principles. *ZDM*, *49*(4), 599-611.

Ryan, R., & Deci, E. (2000). Intrinsic and extrinsic motivations: classic definitions and new directions. *Contemporary Educational Psychology*, 25, 54-67.

Ryan, R. M., & Deci, E. L. (2017). *Self-determination theory: Basic psychological needs in motivation, development, and wellness*. The Guilford Press.

Sawatzki, C., & Sullivan, P. (2018). Shopping for shoes: Teaching students to apply and interpret mathematics in the real world. *International Journal of Science and Mathematics Education*, *16*(7), 1355-1373.

Serpe, R.L.,(2017). Gamification Through Algebraic Coding. *Education and Human Development Master's Theses.* 711.

Singer, J. A., & Salovey, P. (2010). *Remembered self: emotion and memory in personality*. Simon and Schuster.

Stacey Brull, DNP, RN, NE-BC; Susan Finlayson, DNP, RN, NE-BC. (2016). Importance of Gamification in Increasing Learning. *The Journal of Continuing Education in Nursing. 47*(8). 372-375.

School development plan (2017-2020)

School report (2018-2019)

Toda A. M., do Carmo R.S., Mesquita M.A., Silva A.L., and Brancher J.D. (2014). A gamified online system to aid in math lessons of junior and middle high students. In Computer and Information Technology(CIT), IEEE Internationa Conference (pp. 616-621).

Wang, T. D. & Towey, D. (2013). A Mobile Virtual Environment Game Approach for Improving Student Learning Performance in Integrated Science Classes in Hong Kong International Schools. Proceedings of 2013.

Uzun, L., Cetinavci, U. R., Korkmaz, S, & Salihoglu, U. M. (2013). Developing and applying a foreign language vocabulary learning and practice game: The effect of VocaWord. *Digital Culture & Education*, 5(1), pp.48-70.

Xu, X., & Ke, F. (2016). Designing a virtual-reality-based, game-like math learning environment. *American Journal of Distance Education*, 30(1), 27-38.

Yan, Z., & Brown, G. T. L. (2017). A cyclical self-assessment process: Towards a model of how students engage in self-assessment. *Assessment & Evaluation in Higher Education, 42*(8), 1247-1262. https://doi.org/10.1080/02602938.2016.1260091

Yi, H. L. & Chu, Y. Y. (2017). Meaningful Gamification for Journalism Students to Enhance Their Critical Thinking Skills. *International Journal of Game-Based Learning (IJGBL),* 7(2), pp.47-62.

《數學與生活1A》培生出版社。

《數學與生活1B》培生出版社。

《數學與生活2A》培生出版社。

《數學與生活2B》培生出版社。

《數學與生活3A》培生出版社。

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Appendix 1: Topics Covered

(The topics are selected based on the revised secondary Mathematics curriculum.)

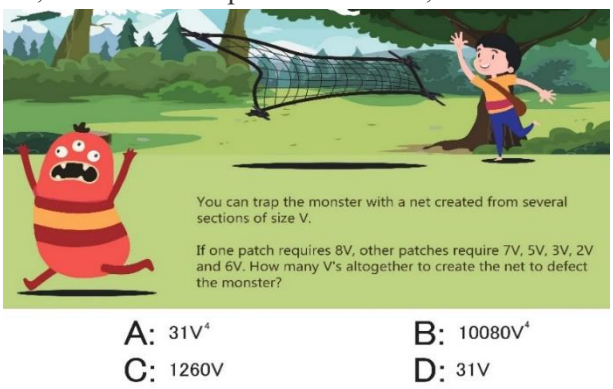
	Unit	**Learning Topic**	**Benefits to Students**
1	Number and Algebra	• Basic computation • Directed numbers	To interpret simple algebraic relations from numerical, symbolic and graphical perspectives
2		• Algebraic expressions • Manipulation of polynomials	
3		• Linear equations in one unknown/two unknowns • Linear inequalities in one unknown	
4		• Using Percentages • Rate, Ratio and Proportions	
5	Measures, Shape and Space	• Mensuration • Arc lengths and areas of sectors • Angles and parallel lines • Polygons	To understand and visualize geometric properties of 2-dimensional and 3-dimensional objects intuitively
6		• Congruent triangles • Similar triangles • Quadrilaterals	
7		• Rectangular coordinate system	
8		• Pythagoras' Theorem • Trigonometry	
9	Data Handling	• Organisation and Presentation of data • Measures of central tendency	To formulate and solve problems arising from collected data and constructed graphs
10		• Probability	

Appendix II. The App design questions

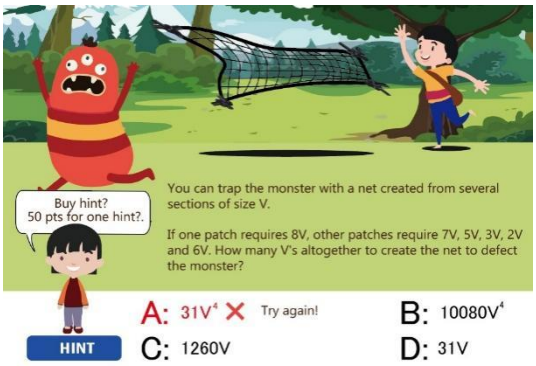
This bright and colourful app is a good way for students to master their S1-S3 mathematics topics. Animal characters represent different degrees of difficulty (Easy, Medium or Hard) that students can select.

The app presents students with a series of questions, each with four possible answers, and the student must pick the right one.

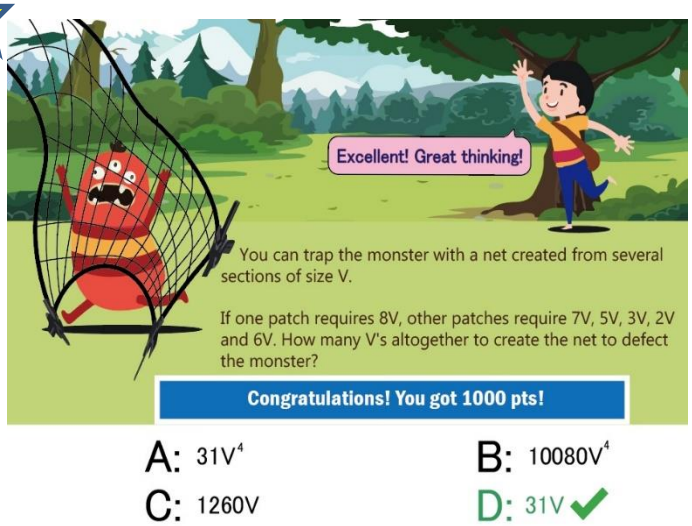
Example 1 - Easy Level question sample (Basic Knowledge)



Wrong answers capture common student mistakes. Each selection of a wrong answer reduces a student's experience points.



Students can use their experience points to buy hints, which can guide students to find the right answer.

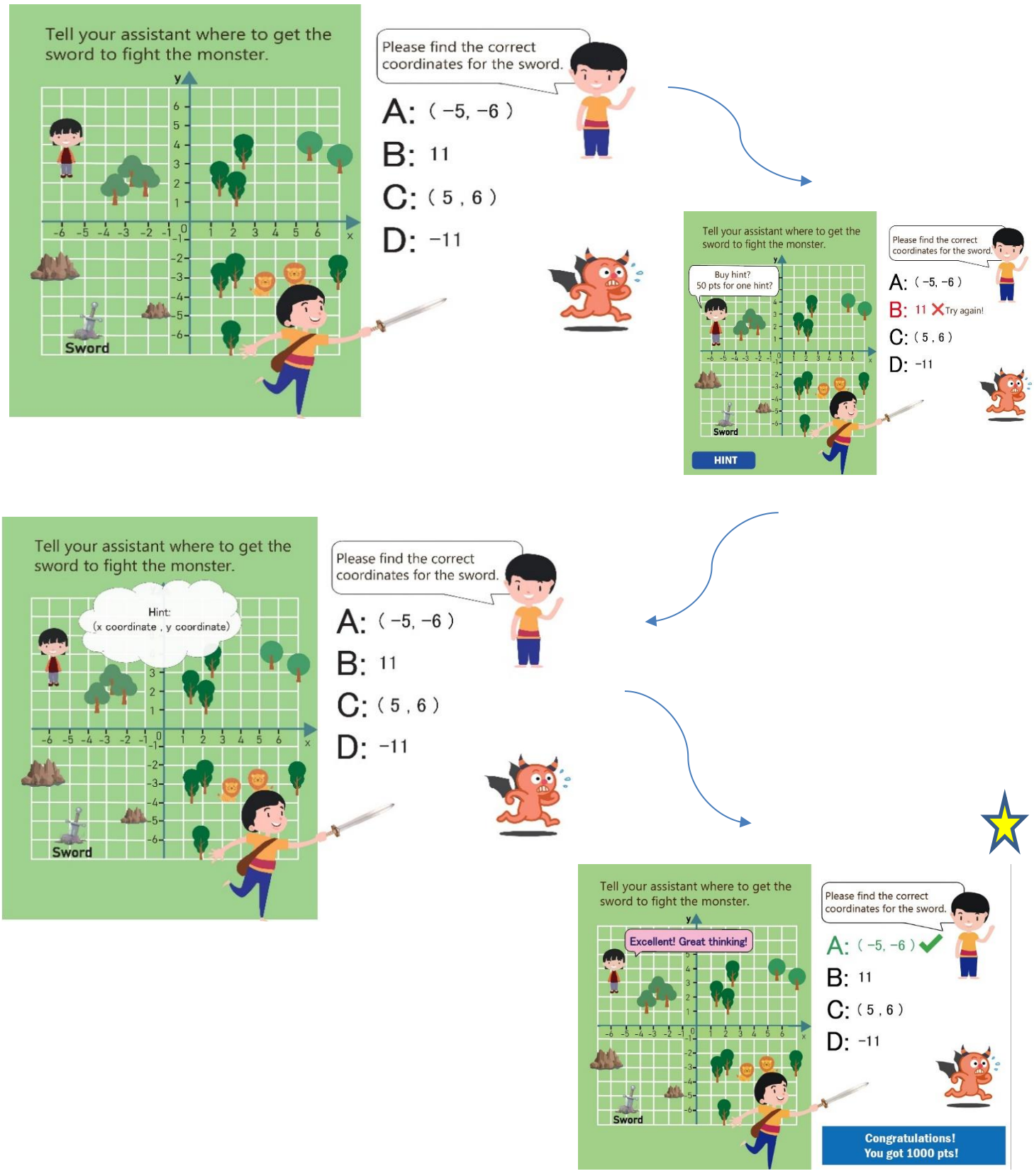


Cheerful sound effects and positive affirmations ('Great thinking!' 'You're a star!') will motivate the students to do well, along with the incentive of earning experience points and challenging their own top scores.

Example 2 - Medium Level question sample

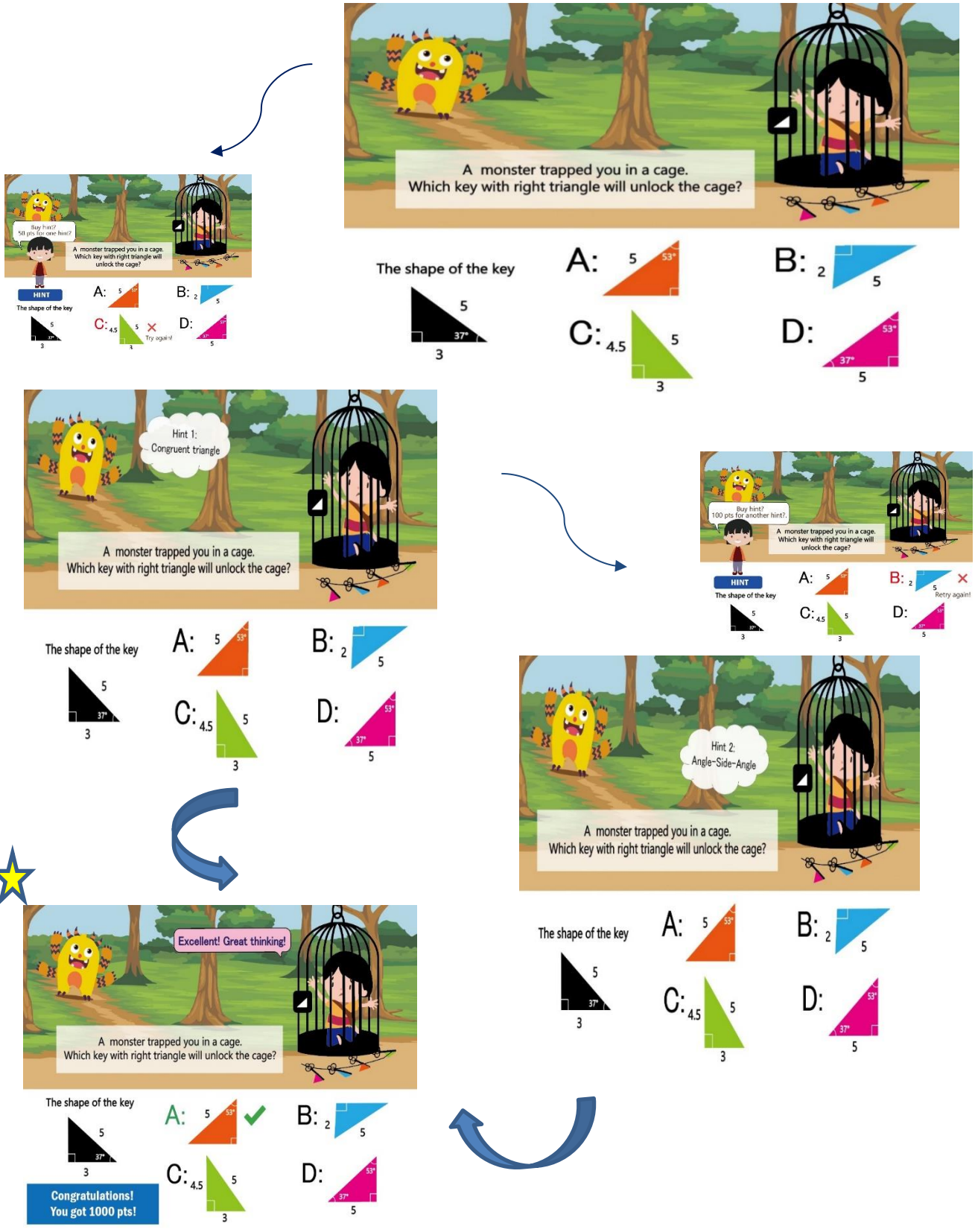
After correctly solving an easy problem, the student receives a harder problem.

(If a student chooses two wrong answers on the previous problem, an easier problem is shown.)

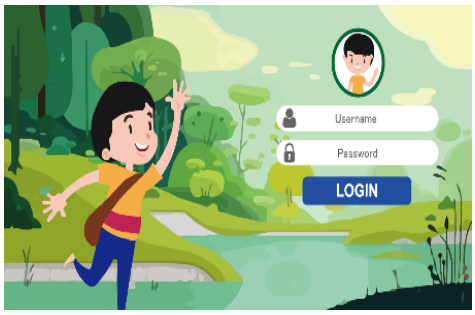


Example 3 - Hard level question sample

Harder problems allow students to buy multiple hints. Following educationally-appropriate *scaffolding* principles, each hint is progressively more helpful (Rittle-Johnson et al., 2017).



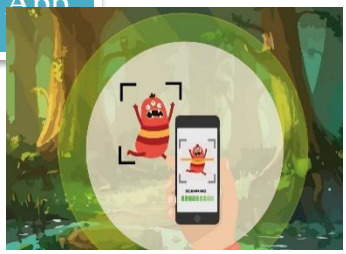
Appendix III. Workflow of a gamified learning process of the MATHero app



Login

The MATHERO'S Journey App

Or



Or

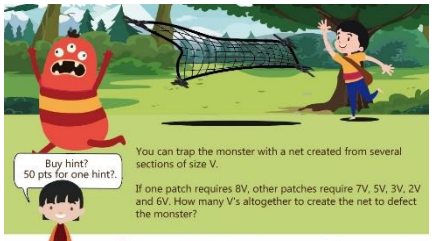
Play
outside the classroom /school playground
Play at home or inside the lesson

GAMES

Assessment (Level 1)

A: $31V^4$ B: $10080V^4$
C: 1260V D: 31V

A: $31V^4$ B: $10080V^4$
C: 1260V D: 31V ✔



A: $31V^4$ ✕ Try again! B: $10080V^4$
C: 1260V D: 31V

Students have to solve problems and gain certain points in order to reach next level.

Level completed!

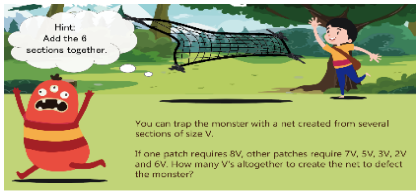
Advance to Level 2

Advance to Level 3

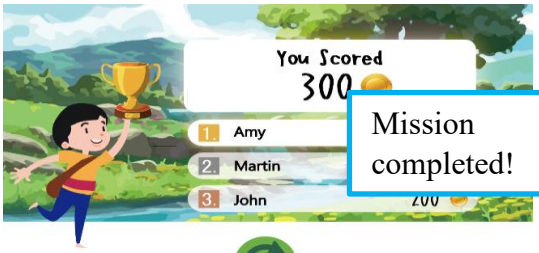
Student buys Hints

Buy1 Hint?

Buy 2 Hints?



A: $31V^4$ B: $10080V^4$
C: 1260V D: 31V



Mission completed!

Play Again?

Appendix IV

Summary of project objectives, success criteria and evaluation methods.

Objectives	**Success Criteria**	**Evaluation methods**
Increase students' motivation to learn mathematics.	Using MATHero's Journey App, more than 50% of the students will be motivated to learn Mathematics.	• Students' perception survey • Crossover experiment • Observation of lessons
Increase student confidence to learn mathematics with technology and interactive elements.	Using MATHero's Journey App, more than 50% of the students will have confidence to learn mathematics with technology and interactive elements.	• Students' perception survey • Crossover experiement • Observation of lessons
Increase students' mathematics conceptual knowledge and skills.	Using MATHero's Journey App, more than 50% of the students will increase their mathematics conceptual knowledge and skills.	• Crossover experiment • Observation of lessons
Assess students' understandings of mathematics' topics.	Able to use MATHero's Journey App to assess students' understandings of mathematics' topics.	• Crossover experiment
Promote student use of education technology inside and outside the classroom.	After using MATHero's Journey App, more than 50% of the students will become more aware of the use of education technology inside and outside the classroom.	• Observation of lessons
Stimulate students' interest in personal formative assessment.	More than 50% of the students will be interested in formative assessment in MATHero's Journey App.	• Students' perception survey • Crossover experiment • Observation of lessons
Equip teachers with professional, engaging technology in the classroom.	Participating teachers are able to use MATHero's Journey App in the classroom.	• Observation of lessons
Provide teachers with an engaging homework option for students to enhance their learning of mathematics.	Participating teachers are able to use the learning materials package to enhance students' learning of mathematics.	• Observation of lessons