An Adaptive Game-Based Diagnostic and Remedial Learning System Based on the Concept Effect Model

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Soochow University

- The Methodists established Soochow University in Suzhou in 1900. (133 years)
- SU was the first western-style university in China.
- SU was re-established in Taiwan in 1954.
- Taiwan's first private university.
- Six colleges, 23 departments and research centers.
- Exceed 150,000 students and 1,200 full/adjunct professors.

Waishuanghsi Campus

Playground

Gates

About Waishuanghsi Campus

- The National Palace Museum is close to the campus.
- There are four colleges and two centers on the campus.
  - School of Arts & Social Sciences
  - School of Foreign Languages and Cultures
  - School of Big Data and management
  - School of Science

  - Center for Big Data Analysis and Research
  - Center for Applied Artificial Intelligence Research

Downtown Campus

Presidential palace

Campus

Supreme Court

About Downtown Campus

- Downtown Campus is located in the most convenience area in Taipei.
- This is the first campus of Soochow University.
- There are full of rich resources nearby—
  - many national administrative units: presidential palace, Ministry of Defense, commercial centers, National Library.
- This campus contains “School of Law (法學院)”, “School of Business (商學院),” and “Extension School”.

MUTEL (Mobile and Ubiquitous Technologies Enhanced Learning) lab

- Funded by NTSC, MOE and MOHW of Taiwan per year for conducting mobile learning programs
  - Science courses
  - Social studies courses
  - Language courses
  - Computer or engineering courses
  - Medical Education

The backgrounds of the members in this lab include Computer Science and Educational Technology.

Language Therapy

Computational Thinking

Mobile/ Ubiquitous Learning

AR/VR

Game-based learning

Digital Humanities

Research interests

- Mobile and Ubiquitous Learning
- Game-based Learning
- Flipped learning
- AI in Education
- Computer-assisted evaluation and diagnosis of learning problems
- Information technology-applied instructions
- The application of knowledge engineering

Academic rewards

- **2014, Annual Young Scholars Outstanding Researcher Award--Ta-You Wu Memorial Award** by Ministry of Science and Technology.(吳大猷先生紀念獎)
- The Distinguished Young Scholar Project by MOST(2012-2014)(優秀年輕學者計畫)
- The MOST Special Outstanding Talent Award by MOST (2011-2023) (國科會特殊優秀人才獎勵)
- Outstanding ICT Elite Award (2020)(傑出資訊人才獎)
- KT Li Women's Outstanding Research Award (2022) (李國鼎女性傑出研究獎)

Classroom, Ubiquitous, Mobile learning and technology-enhanced learning (CUMTEL SIG)

- Serving the convener of CUMTEL SIG in Taiwan 2015-2019.

The annual result presentation of “Information Education discipline” of MOST in 2016.

Mobile learning community in Taiwan

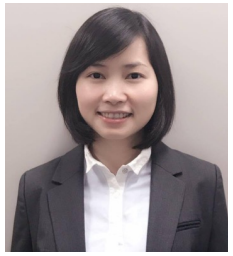
- Researchers from 10 universities in Taiwan
- Sharing research experiences and results every year

International research cooperation


- Japan: Prof. Hiroaki Ogata' team in Kyushu University and Prof. Chengjiu Yin in Kyushu University.
- American & Canada: Prof. Kinshuk's team of the College of Information in the University of North Texas and Athabasca University.
- Thailand: Prof. Patcharin Panjaburee and Prof. Niwat Srisawasdi in Khon Kaen University.
- Hong Kong: Prof. Chee-Kit Looi in The Educational University of Hong Kong.
- UK: Prof. Jingyun Wang, Department of Computer Science, Durham University.







The FLGI 100 (2018)

- The top 50 Flipped Learning leaders in higher education worldwide

http://flr.flglobal.org/?p=115

Academic Publications of MUTEL Lab

- 68 journal papers (38 SSCI, 8 SCI)
  - Computers & Education (SSCI)
  - Educational Technology & Society (SSCI)
  - Innovations in Teaching and Education International (SSCI)
  - British Journal of Educational Technology (SSCI)
  - Electronic Library (SSCI)
  - Interactive Learning Environment (SSCI)
  - Australasian Journal of Educational Technology (SSCI)
  - Expert Systems with Applications (SCI)
  - Other SCI/EI/TSSCI journals
- 90+ papers presented in conferences
- 1 book chapters (in English)
- 3 book chapters (in Chinese)

Academic services

- IEEE Transactions on Learning Technologies (SSCI, Q1). Associate Editor
- Interactive Learning Environments (SSCI, Q1) in 2013 and 2016. Guest editor
- International Journal of Online Pedagogy and Course Design (IJOPCD) (EI: INSPEC) Guest editor March 31, 2022
- International Journal on Digital Learning Technology- Guest editor (數位學習科技期刊)(TSSCI)
- Journal of Internet (SCIE)- Associate Editor

Abstract

- Although game-based learning strategies have been used in mathematics education for a period of time, the potential for enhancing students' learning achievement and math self-efficacy is still being explored.
- Even though using games to learn mathematics may enhance students' motivation, without efficiently personalized learning guidance, students may not be able to learn well in games.
- Adaptive educational games provide opportunities to give students personalized learning content and guidance.

Abstract

- The concept-effect relationship (CER) is an effective tool for the organization of learning material in developing adaptive diagnostic systems for detecting students' learning problems.
- A concept-effect relationship and an interactive game-based learning system were conducted as an effective tool for the organization of learning material in developing a diagnostic and remedial system for detecting students' learning problems.

Introduction

- The concept-effect relationship (CER), a well-studied strategy in teaching and learning guidance, has gained significant traction in the field of educational diagnosis models due to the rapid advancement of technological instruction (Hwang, 2003; Lin, Chang, Liew, & Chu, 2015).
- Game-based learning has been found to enhance students' active engagement in learning activities and promote higher order thinking, as reported by multiple studies.
- In this study, an adaptive concept-effect relationship (CER)-based mathematics game system was developed for conducting mathematics diagnostic and remedial learning activities.

A conceptual map for developing intelligent tutoring systems (2003)

- How to use computer networks to ***develop computer-aided instruction systems*****?**
- Conventional testing systems simply give students a score, but don't give them the opportunity to learn ***how to improve their learning performance***.
- Students would benefit more if the test results could be **analyzed** and hence **advice** could be provided accordingly.
- This study proposes a conceptual map model, which provides ***learning suggestions*** by analyzing the subject materials and test results.

Conceptual map (McAleese, 1994, 1998)

- Students learn ***new concepts*** and new relationships among ***previously learned concepts*****.**
- This knowledge can be represented as a *conceptual map****.***

Concept effect relationships (Salisbury, 1998).

- ***Learning information***: including facts, names, labels, or paired associations, is often a prerequisite to efficiently performing a more complex, higher level skill.
- Relationships exist that indicate the **effect of learning one concept on the learning of other concepts**.
- Such conceptual maps diagrammatically as ***"concept effect graphs"***.

Structure of subject materials & conceptual map model

- Subject materials can be viewed as a ***tree diagram*** comprising chapters, sections, sub-sections and key concepts to be learned.

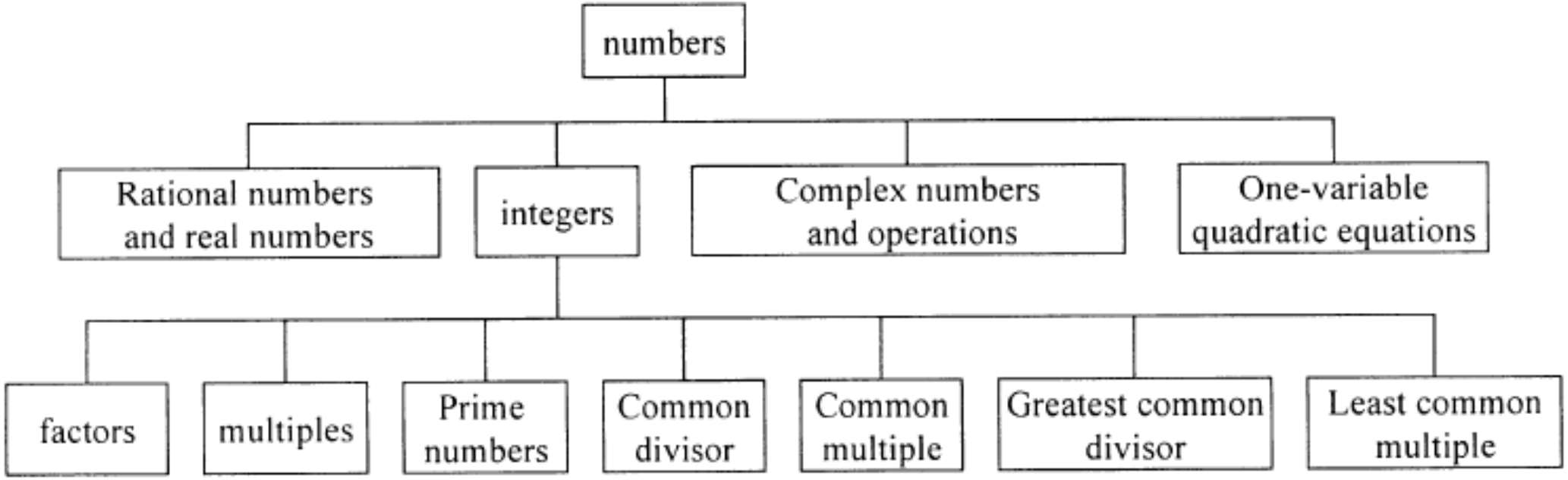
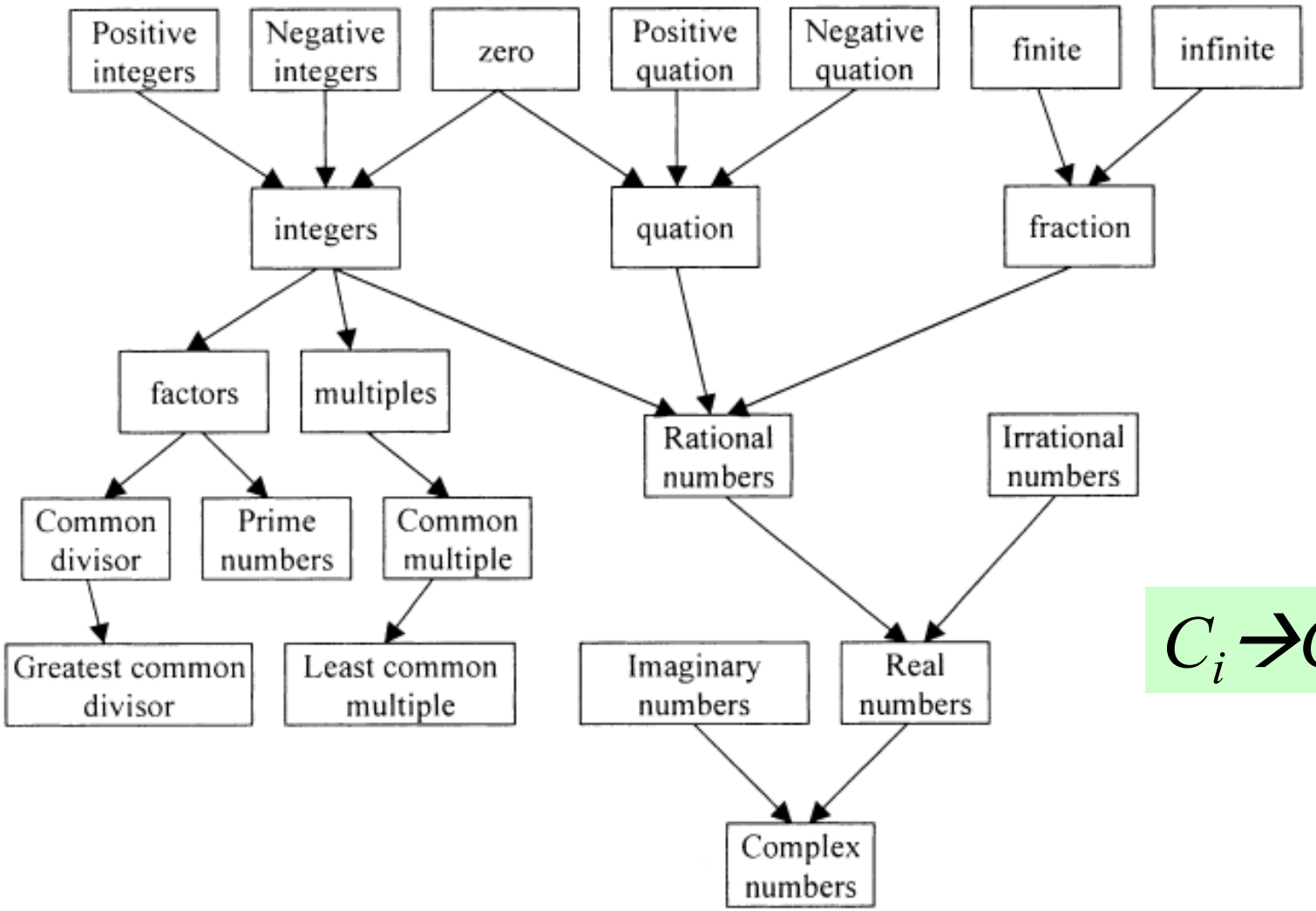


Fig. 1. Tree structure for "numbers".

Concept effect Relationships



$C_i \rightarrow C_j$

Fig. 2. Concept effect graph for the subject unit "numbers".

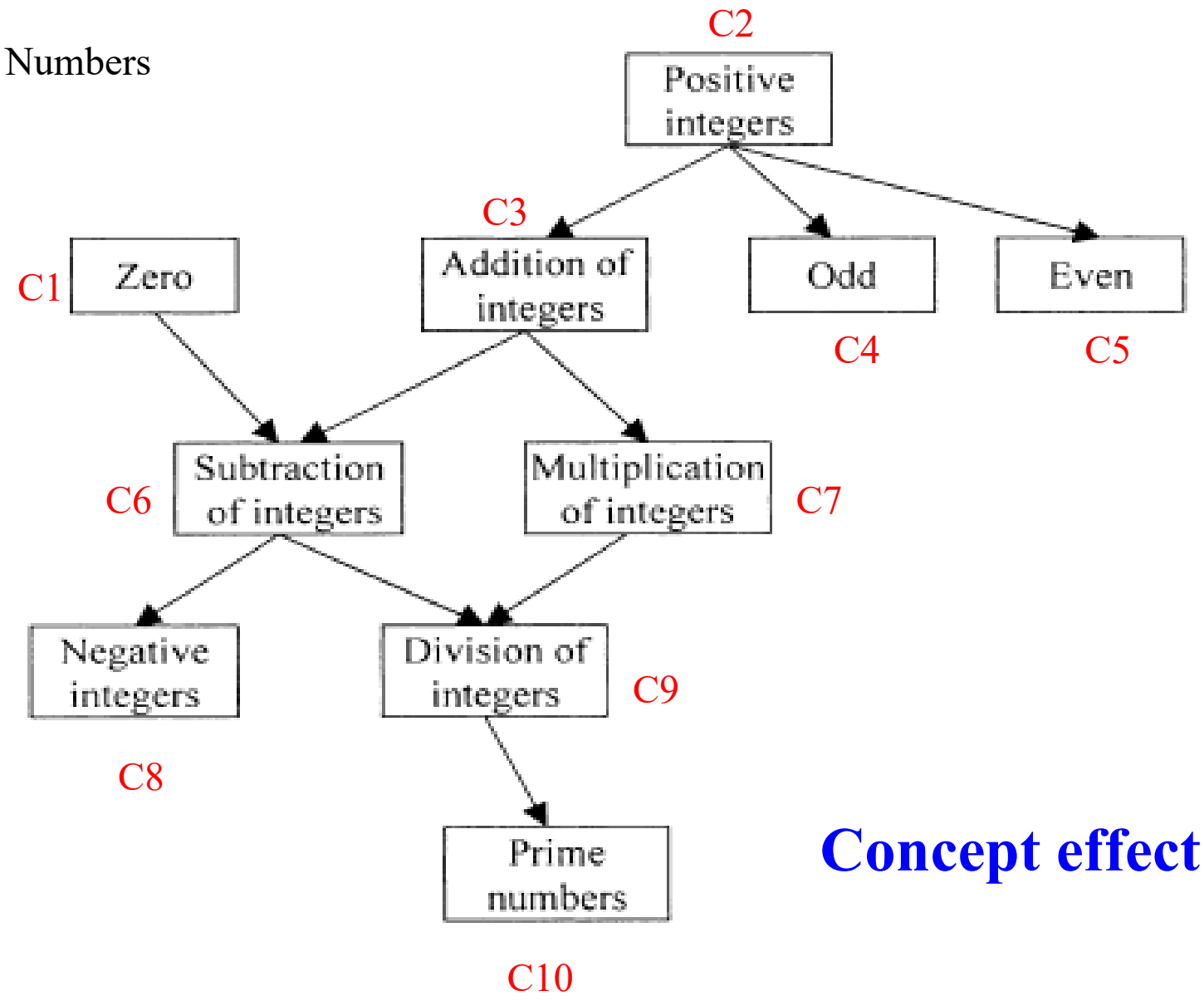
Concept effect table (CET)

- Two-dimensional table.
- If CET(C_i,C_j)=1, it is said that "C_i is one of the prerequisites of C_j".

Table 1
Illustrative example of a concept effect table

Prerequisite (C_i)	C_j									
	C_1 (Zero)	C_2 (Positive integers)	C_3 (Addition)	C_4 (Odd)	C_5 (Even)	C_6 (Subtraction)	C_7 (Multiplication)	C_8 (Negative integers)	C_9 (Division)	C_{10} (Prime numbers)
C_1	0	0	0	0	0	1	0	0	0	0
C_2	0	0	1	1	1	0	0	0	0	0
C_3	0	0	0	0	0	1	1	0	0	0
C_4	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
C_6	0	0	0	0	0	0	0	1	1	0
C_7	0	0	0	0	0	0	0	0	1	0
C_8	0	0	0	0	0	0	0	0	0	0
C_9	0	0	0	0	0	0	0	0	0	1
C_{10}	0	0	0	0	0	0	0	0	0	0
NP_j	0	0	1	1	1	2	1	1	2	1

G.-J. Hwang / Computers & Education 40 (2003) 217–235



Concept effect graph

Illustrative example of a test item relationship table (TIRT)

Q_i	C_j									
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Q_1	5	1	0	0	0	0	0	0	0	0
Q_2	0	4	2	0	0	0	0	0	0	0
Q_3 *wrong*	0	0	3	1	2	0	0	2	0	0
Q_4								0	0	0
Q_5								0	0	0
Q_6 *wrong*	1	0	0	0	0	4	0	2	0	0
Q_7 *wrong*									0	0
Q_8									1	0
Q_9 *wrong*	0	0	0	0	0	0	0	0	4	5
Q_{10}	0	0	0	0	0	2	0	1	0	0
SUM	6	5	5	6	7	6	6 8	5	5	5
ERROR	1	0	3	1	2	4	4 5	4	4	5
ER(C_j)										
	=1/6	=0/5	=3/5	=1/6	=2/7	=4/6	=5/8	=4/5	=4/5	=5/5

The total weight of the Concept Cj in the test

The total weight of the wrong answer Concept Cj

ER(C_1) ER(C_2) ER(C_3)

Test item relationship table (TIRT)

- 10 tests items: $Q_1, Q_2, Q_3, \ldots Q_{10}$
- **TIST(Q_i,C_j)**: ranging from 0~5
  (0: no relationship; 1~5: the intensity of the relationship)
- **SUM(C_j)**: denotes the total strength of *concept* C_j in the test sheet
- **ERROR(C_j)**: the total strength of the *incorrect answers* which are related to C_j
- **ER(C_j)= ERROR(C_j)/SUM(C_j)**: the ratio of incorrect answers to the total strength of concept C_j

Add each concept's ER(Cj)

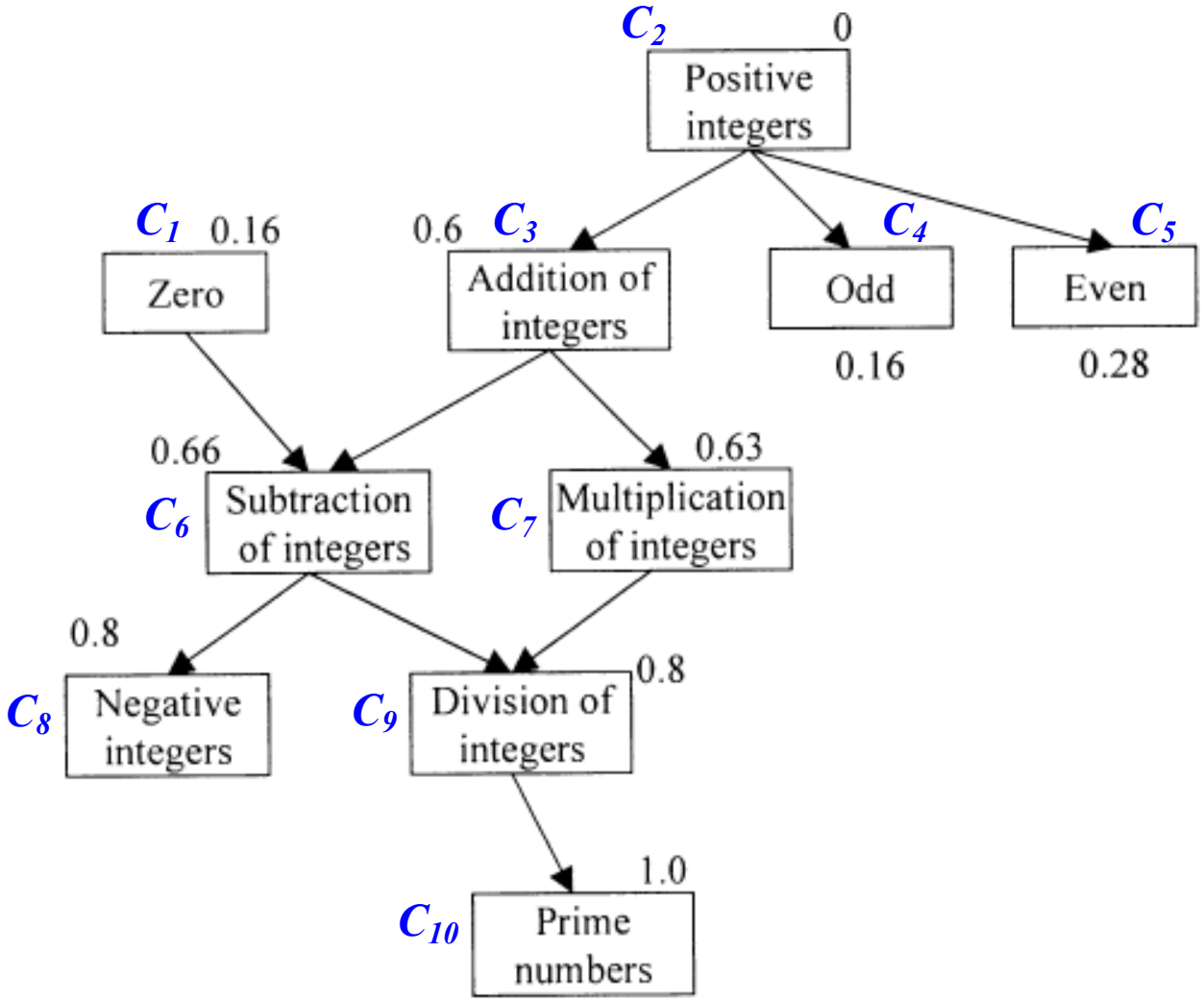


Fig. 4. Illustrative example of a concept effect graph with ER values.

Learning diagnosis procedure--θ

- **θ=MIN(ER(C_j))** : threshold, θ, indicate the acceptable error rate
- **ER(C_j)<θ**: have learned C_j
- **ER(C_j)>θ**: ***To-Be-Enhanced learning path***

- **LB(C_j)**: lower bound of error ratios of each concepts.

=> the average error ratio of C_j for the students who get the bottom 50% of test scores.

- Calculated the difference in the student error ratio for concepts C_j and LB(C_j)
- **DIFF(C_j)=ER(C_j) - LB(C_j)** { **DIFF(C_j)<0, Finished learning**; **DIFF(C_j)>0, Organize Learning Paths**

Test item relationship table (TIRT)

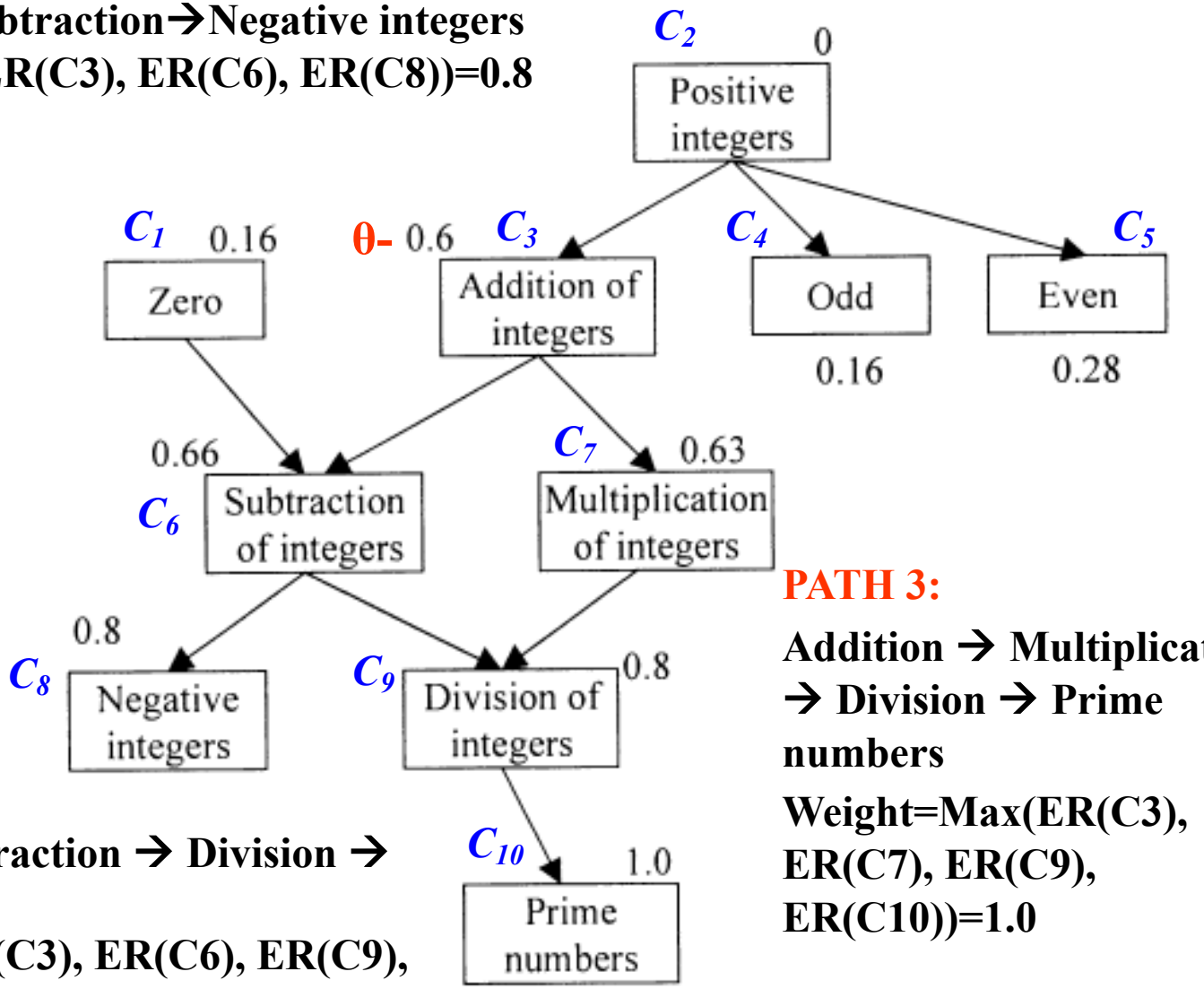
Q_i	C_j									
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Q_1	5	1	0	0	0	0	0	0	0	0
Q_2	0	4	2	0	0	0	0	0	0	0
Q_3	0	0	3	1	2	0	0	2	0	0
Q_4	0	0	0	5	0	0	0	0	0	0
Q_5	0	0	0	0	5	0	0	0	0	0
Q_6	1	0	0	0	0	4	0	2	0	0
Q_7	0	0	0	0	0	0	5	0	0	0
Q_8	0	0	0	0	0	0	0	0	1	0
Q_9	0	0	0	0	0	0	0	0	4	5
Q_{10}	0	0	0	0	0	2	0	1	0	0
SUM (a)	6	5	5	6	7	6	6	5	5	5
ERROR (b)	1	0	3	1	2	4	4	4	4	5
ER(C_j) (c)=(b)/(a)	0.16	0	θ= 0.6	0.16	0.28	0.66	0.63	0.8	0.8	1.0
LB(Cj) (d)	0.33		0.5	0.4	0.33	0.45	0.5	0.66	0.5	0.66
DIFF (c)-(d)	-0.17		0.10	-0.24	-0.05	0.21	0.13	0.14	0.30	0.34

LB(Cj)(lower bound) was obtained by calculating the average error rate of these students on the concept Cj in the latter part of the assessment.

PATH 1:

Addition → Subtraction→Negative integers

Weight=Max(ER(C3), ER(C6), ER(C8))=0.8



PATH 2:

Addition → Subtraction → Division → Prime numbers

Weight=Max(ER(C3), ER(C6), ER(C9), ER(C10))=1.0

PATH 3:

Addition → Multiplication → Division → Prime numbers

Weight=Max(ER(C3), ER(C7), ER(C9), ER(C10))=1.0

The best path: PATH 2 & PATH 3 = Max Weight

Concept-effect relationship

- An illustrative example of the concept–effect relationships among C1, C2, C3, and C4.
- For example, if a student fails to answer most of the test items concerning “C4 Fractional multiples,” the problem is likely that the student has not thoroughly understood “fractional multiples” or its prerequisite concepts (such as “subtraction of fractions” or “multiplication of integers”).

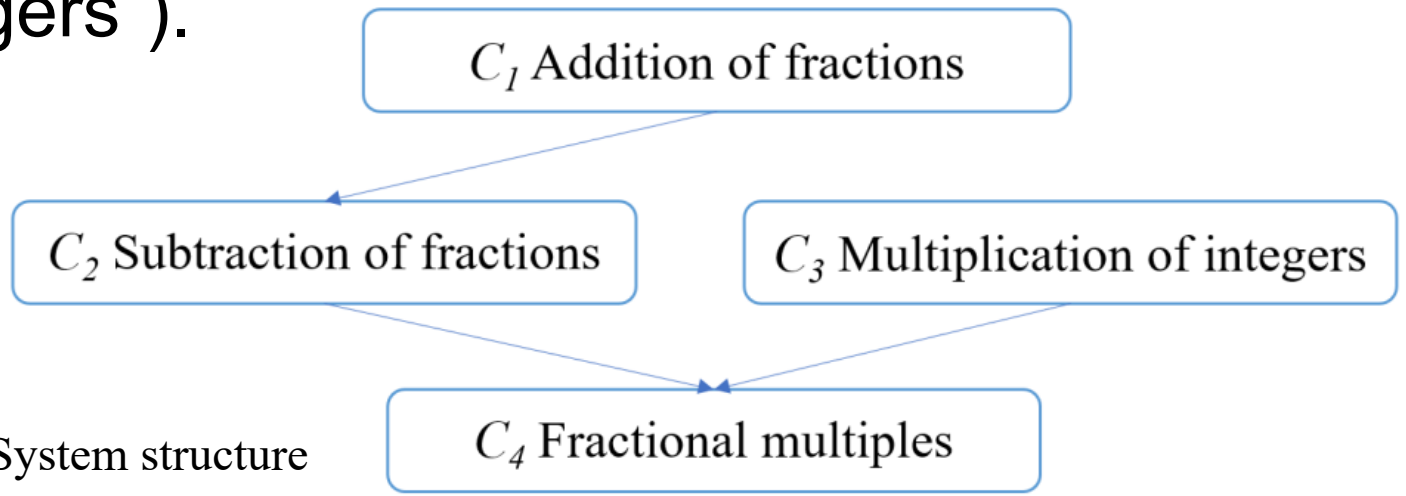
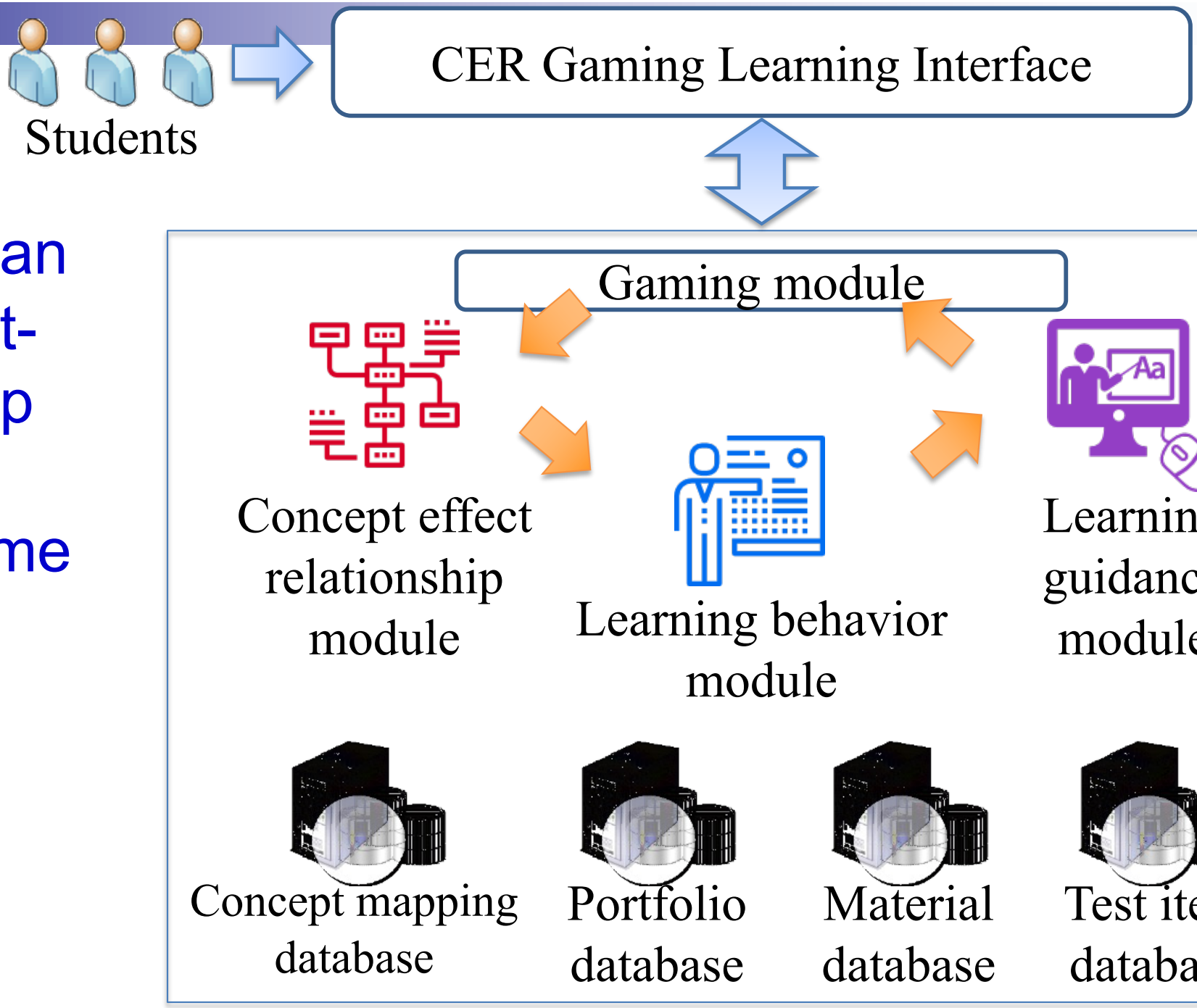


Figure 1. System structure

Personalized and adaptive digital game-based learning

- Researchers have found that digital games offer a contextual learning environment that allows students to interact with games and appropriate media, enabling them to explore complex learning content and concepts (Ke, 2009; Chang, Kao, Hwang, & Lin, 2020).
- Hwang et al.,(2012) proposed a cognitive analysis approach to develop a spatial game-based learning system. Students could learn the spatial concepts while performing different learning tasks such as matching games, treasure hunting, and recognizing different angles.
- Vanbecelaere et al. (2021) proposed an adaptive digital educational game named the Number Sense Game (NSG) to teach children their early numerical abilities.

Development of an adaptive concept-effect relationship (CER)-based mathematics game



Assessment model of an adaptive CER-based mathematics game

Step 1: Establish the concept-effect relationship (CER)

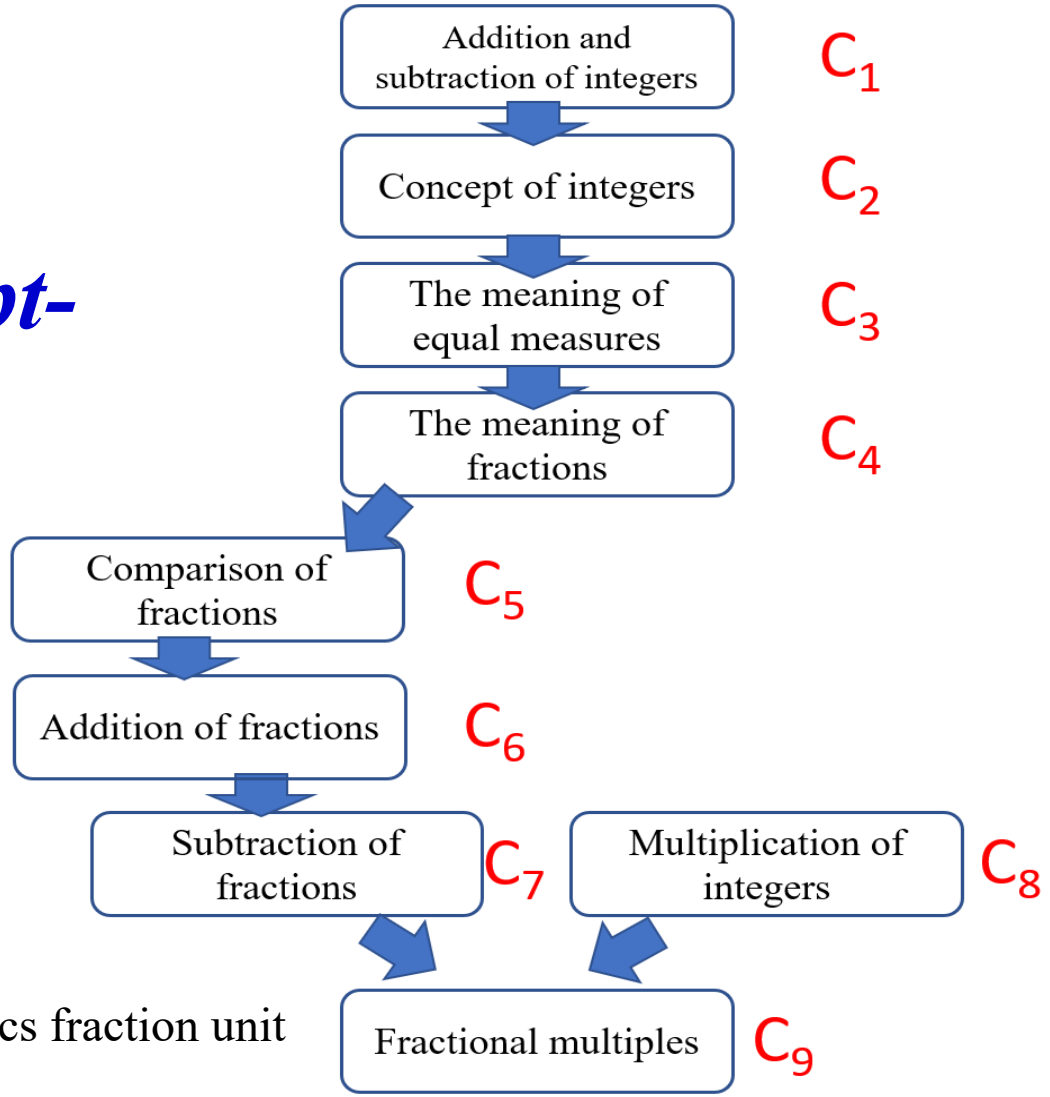


Figure 3. Diagram of CER for the mathematics fraction unit

Step 2: Calculate the student's understanding of different concepts

- In order to grasp a student's span of comprehension for each concept, the relationship between learning concepts and test questions is developed by domain experts based on the CER diagram and test questions.

Table 1. Relevance between concepts and test questions

		C_j								
		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
Q_i	Q_1	1	3	0	0	0	0	0	0	0
	Q_2	5	2	3	0	4	3	0	0	0
	Q_3	3	2	2	0	5	3	0	0	0
	Q_4	0	0	2	1	0	4	0	0	0
	Q_5	0	0	0	2	0	0	1	1	0
	Q_6	0	0	0	4	0	0	0	0	0
	Q_7	1	2	0	0	0	0	2	0	0
	Q_8	0	0	0	2	0	0	0	2	0
	Q_9	0	0	0	0	0	0	0	0	4
	Q_{10}	0	0	0	0	0	0	0	0	1
	Sum	10	9	7	9	9	10	3	3	5
	Error(C_j)	3	3	1	2	4	7	2	1	2
	ER(C_j)	0.3	0.33	0.14	0.22	0.44	0.7	0.66	0.33	0.4

$Sum(C_1)=1+5+3+1=10$; $Sum(C_2)=3+2+2+2=9$; $Sum(C_3)=3+2+2=7$
$Sum(C_4)=1+2+4+2=9$; $Sum(C_5)=4+5=9$; $Sum(C_6)=3+3+4=10$
$Sum(C_7)=1+2=3$

Error(C1)=3 ; Error(C2)=3 ; Error(C3)=1 ; Error(C4)=2 ; Error(C5)=4 ;
Error(C6)=7 ; Error(C7)=2 ; Error(C8)=1 ; Error(C9)=2 ;

ER(C1) =3/10=0.3 ; ER(C2)=3/9=0.33 ;
ER(C3)=1/7=0.14 ; ER(C4)=2/9=0.22 ;
ER(C5) =4/9=0.44 ; ER(C6)=7/10=0.7 ;
ER(C7)=2/3=0.66 ; ER(C8)=1/3=0.33 ;
ER(C9) =2/5=0.4

Table 2. Individual students' answering status

	Test item Q_k									
Student S_i	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8	Q_9	Q_{10}
S_1	1	1	1	0	1	1	0	1	1	1
S_2	1	0	1	0	1	0	1	1	0	1
S_3	1	0	1	1	1	1	0	1	1	1
S_4	0	1	1	1	0	0	1	1	0	1
S_5	1	0	0	0	1	1	1	1	1	1
S_6	1	1	1	1	1	1	1	0	1	1
S_7	0	1	1	1	0	1	0	1	0	0
S_8	1	0	0	0	1	0	1	1	1	1
S_9	1	1	1	1	1	1	1	0	1	0
S_{10}	1	1	1	1	1	0	1	1	1	1

Table 2 reflects the number of errors of concept Cj for the student in the test, Error (Cj), and the error rate of the student's answer for each concept Cj, shown with the formula ER(Cj) = Error(Cj)/Sum.

- Individual students' span of comprehension for each concept is calculated on the basis of the CER diagram with error rate, as shown in Figure 4.

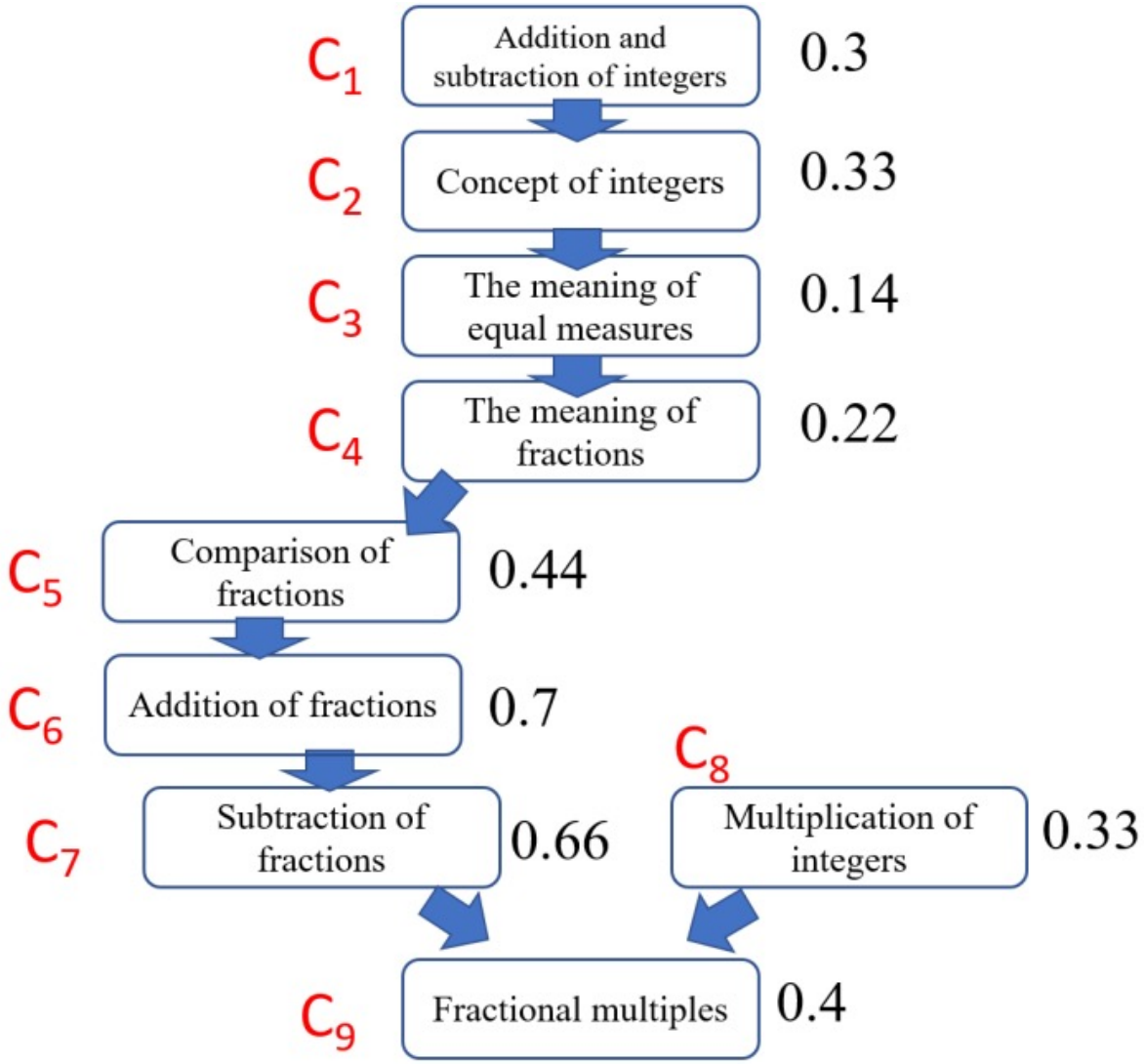


Figure 4. Diagram of weighted CER for fractions with the error rate

Step 3: Learning diagnosis and feedback

- The system finds out the error rate of the student's answer for each concept, and the relationship among concepts.
- Suppose that the mathematics teacher sets up the threshold for wrong answers to each concept as α = 0.28, which means that the error rates of concepts exceed the threshold, and the system will provide the student with a remedial course for the wrong concepts.

$ER(C1) = 0.30 > \alpha(=0.28)$
$ER(C2) = 0.33 > \alpha(=0.28)$
$ER(C3) = 0.14 < \alpha(=0.28)$
$ER(C4) = 0.22 < \alpha(=0.28)$
$ER(C5) = 0.44 > \alpha(=0.28)$
$ER(C6) = 0.70 > \alpha(=0.28)$
$ER(C7) = 0.66 > \alpha(=0.28)$
$ER(C8) = 0.33 > \alpha(=0.28)$
$ER(C9) = 0.40 > \alpha(=0.28)$

Path 1: C1→C2
Path 2: C5→C6→C7→C9
Path 3: C8→C9

System interface and game content

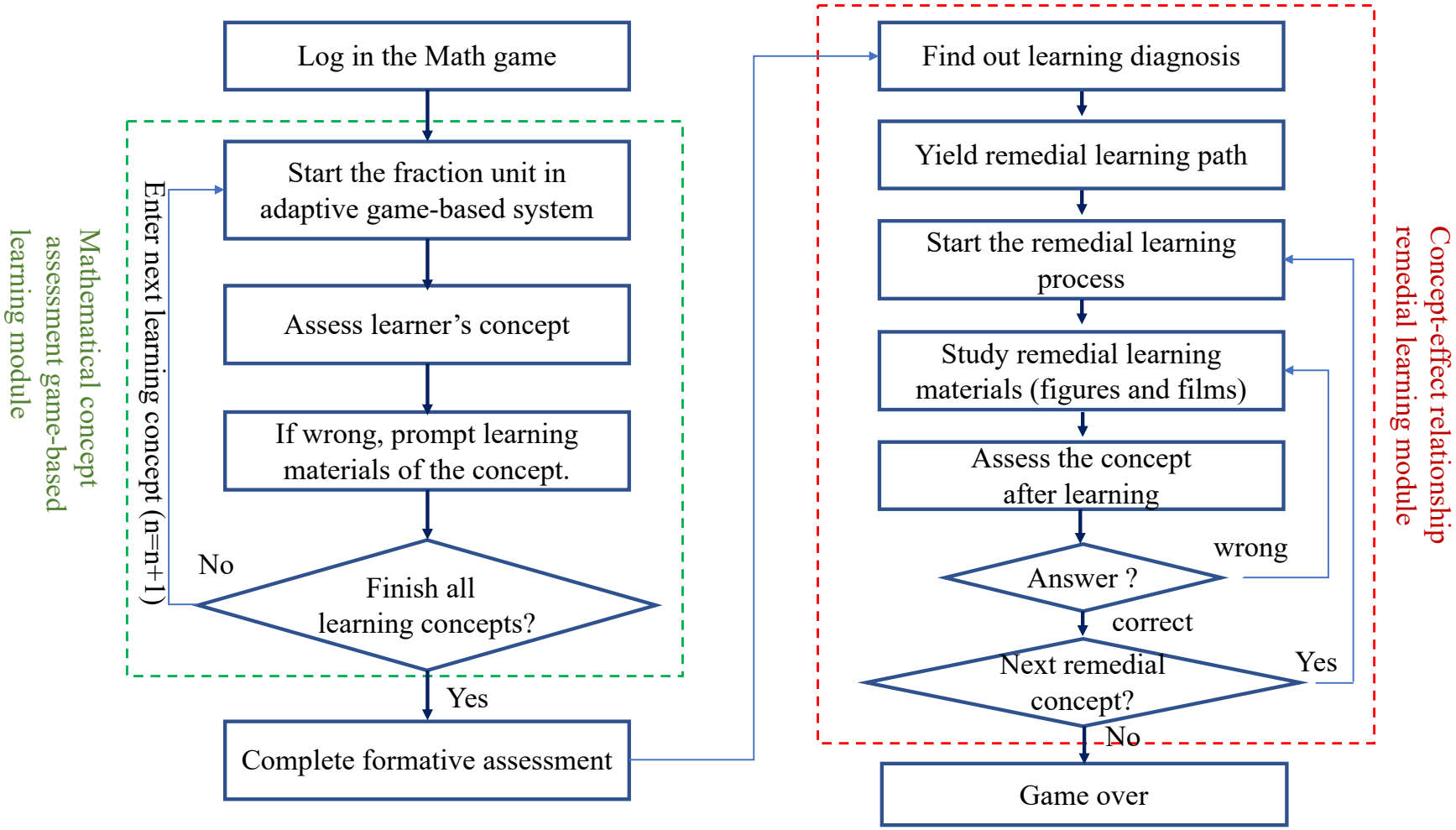


Figure 5. Flowchart based on the CER diagram of the game

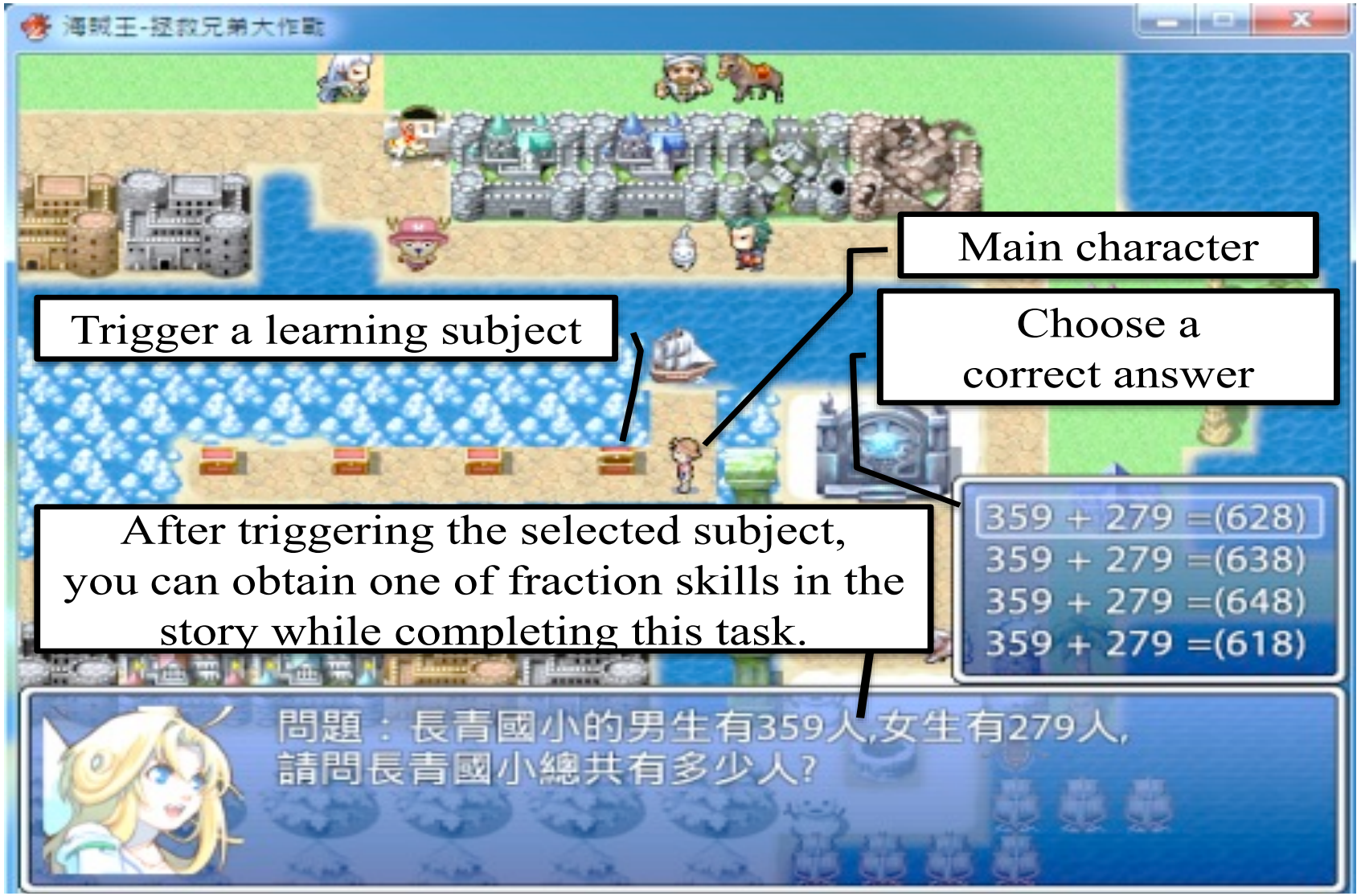


Figure 6. Gaming scenario of triggering the fraction task

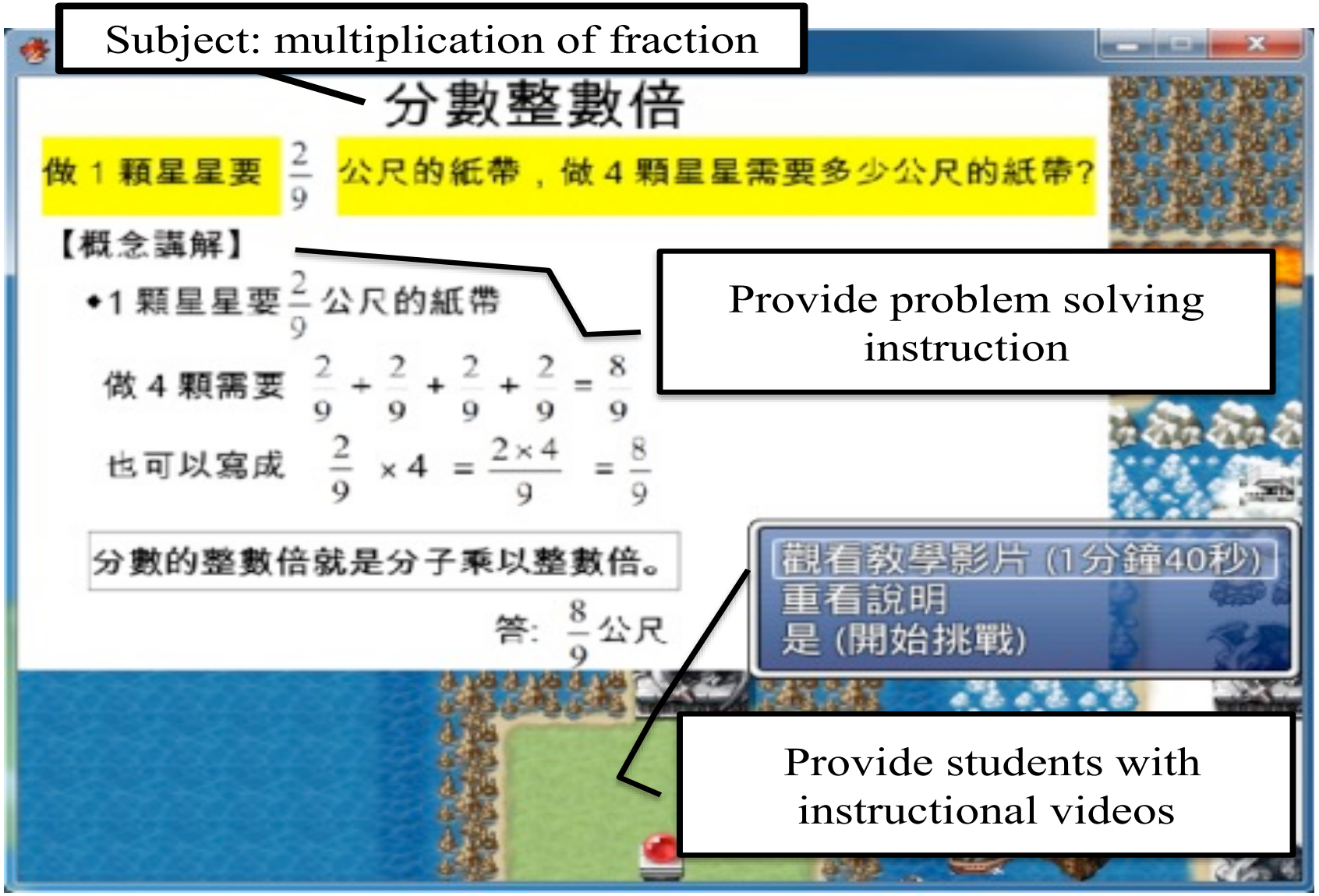


Figure 7. Illustrative example of learning guidance

Figure 8. Screenshot of a student's correct answer

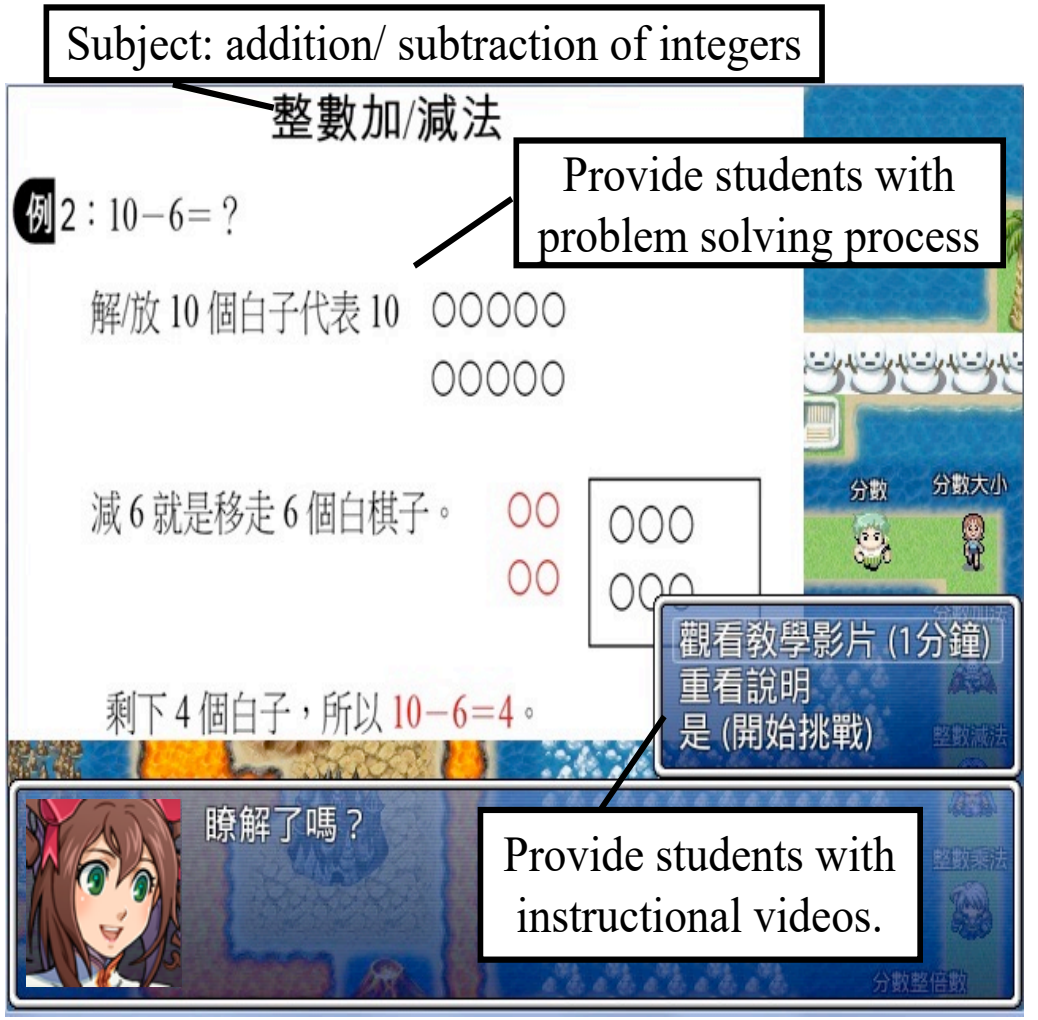


Figure 10. Process of a remedial course

Participants

- 116 third-grade students in two classes of an elementary school in northern Taiwan.
- A quasi-experiment was designed by assigning the students in one class to the experimental group (26 males and 32 females)
- while the other class was assigned to the control group (30 males and 28 females).

Figure 11. CER game-based learning scenarios for students

Experiment procedure

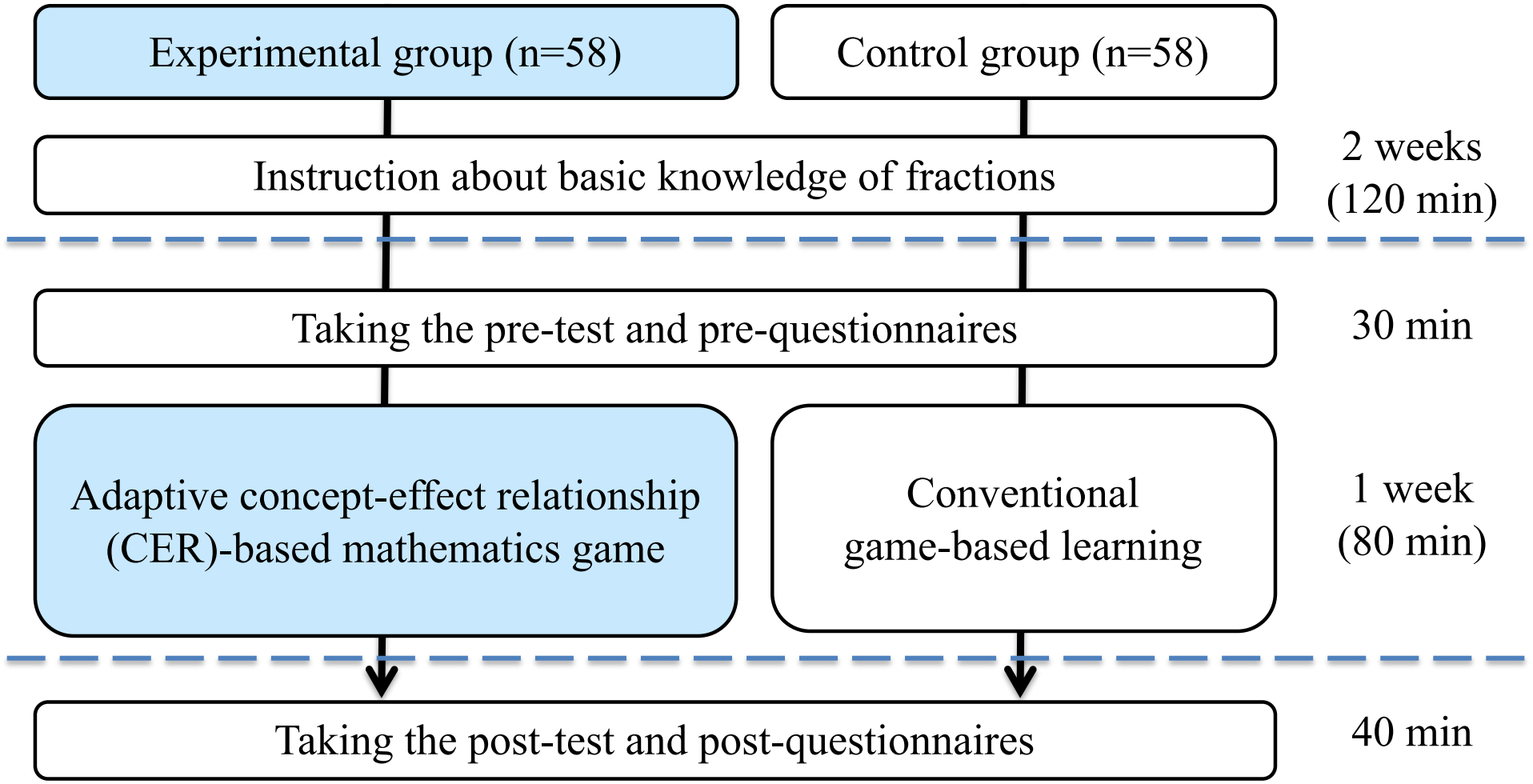


Figure 12. Experiment procedure

Measuring tools

- Learning achievement
  - The pre-test aimed to identify any differences in the students' prior knowledge of learning the course unit.
  - eight mathematics word problems, giving a perfect score of 100.
  - The post-test consisted of four matching problems and 20 mathematics word problems for assessing the students' knowledge of the fraction unit in mathematics.

The questionnaires

- Learning attitude and self-efficacy
  - The Cronbach's alpha value of the questionnaire reaches 0.91, which shows the high internal consistency and reliability of the scale (Cohen, 1988; Bryman & Cramer, 1997).
- Cognitive load
  - Two dimensions, mental load and mental effort.
  - The Cronbach's alpha values of the two dimensions are 0.92 and 0.90, respectively.

Experimental results

Analysis of learning achievement

- Pre-test
- The pre-test scores were 72.10 and 16.37 for the control group, and 70.31 and 17.19 for the experimental group. Here, the *t*-test result ($t = -0.575$, $p > .05$) reveals that the control and experimental groups were not significantly different.

- This study performed a one-way independent-samples analysis of covariance (ANCOVA) to examine the difference between the two groups on the students' fraction performance.
- The students who learned with the adaptive CER-based mathematics game showed significantly better learning achievements than those who learned with the mathematics game without the concept-effect relationship (CER) approach.

Table 3. ANCOVA results of the post-test scores

Groups	*N*	Mean	*S.D.*	Adjusted mean	Std. error	*F*	η^2
Experimental group	58	78.03	11.46	78.37	1.49	17.85^{***}	0.14
Control group	58	69.81	14.15	69.48	1.49		

Note. $^{***}p < .001$.

Analysis of mathematics self-efficacy

- Before the learning activity, there was no significant difference between the two groups (t = 0.358, p>.05)
- After the learning activity, the self-efficacy of the two groups showed significant improvement (mean 3.94 → 4.09 in the control group, and 3.97 →4.44 in the experimental group).
- The experimental group is significantly better than the control group(F=14.25 , p<.001)

➔ The group learning self-efficacy of the experimental group is better than the control group.

Table 4. ANCOVA results of self-efficacy of the two groups

Groups	*N*	Mean	*S.D.*	Adjusted mean	Std. error	*F*	η^2
Experimental group	58	4.44	0.48	4.44	0.66	14.25***	0.11
Control group	58	4.09	0.52	4.09	0.66		

Note. ***$p < .001$.

Analysis of learning attitudes

- Before the learning activity, there was no significant difference between the two groups (t = -0.74, p>.05)
- After the learning activity, the learning attitudes of the two groups showed significant improvement (mean 4.00 → 4.15 in the control group, and 3.93 →4.55 in the experimental group).
- The experimental group is significantly better than the control group(t= 3.79^{***}, p<.001)

→ the learning attitudes of the students in the experimental group were significantly more positive than those of the students who learned with the game without the concept-effect relationship approach.

Table 5. The independent *t*-test results of learning attitudes for the two groups

	Group	*N*	Mean	*S.D.*	*t*	*d*
Pre-test	Experimental Group	58	3.93	0.55	-0.74	0.13
	Control Group	58	4.00	0.49		
Post-test	Experimental Group	58	4.55	0.57	3.79^{***}	0.72
	Control Group	58	4.15	0.54		

Note. $^{***}p < .001$.

Analysis of cognitive load

- Mental effort

there is no significant difference between the two groups of students (t = -1.01; p > .05).

- Mental load

Mental load is concerned with intrinsic cognitive load, which represents the degree to which students need to engage in cognitive processing in order to handle the challenging tasks.

Table 6. The independent *t*-test result of the cognitive load of the two groups

	Group	*N*	Mean	*S.D.*	*t*	*d*
Mental effort	Experimental Group	58	2.89	1.31	-1.01	0.19
	Control Group	58	3.12	1.06		
Mental load	Experimental Group	58	2.21	1.11	-2.46*	0.45
	Control Group	58	2.74	1.23		

Note. $^{*}p < .05$.

Analysis of cognitive load

- There was a significant difference in the mental load of the two groups (*t* = -2.46; p < .05; d = 0.45).
- In addition, the independent *t*-test results of cognitive load reached a moderate effect size for mental load.
- Owing to using the concept-effect relationship approach, the students could engage in deeper understanding in conceptual-knowledge learning, especially those who had difficulty with the learning material, and it reduced their burden in the learning process.

Discussion and conclusions

- In this study, an adaptive concept-effect relationship (CER)-based mathematics game was developed for conducting mathematics learning activities.
- The experimental results demonstrated that, in comparison with the adaptive CER-based mathematics game with conventional game-based learning, the proposed approach significantly improved the students' learning.

Discussion and conclusions

- Future work
  - The investigation of the proposed approach combined with a cooperative learning strategy, Team Assisted Individualization (TAI), can be probed to determine the effectiveness of team-based learning support in mathematics.
- It is necessary to strengthen the system function for teachers to construct CER diagrams quickly and properly.

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Thank you for your listening. Discussion