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Video watching and hands-on experiments to learn science: what can each uniquely contribute?

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Abstract
An experimental group and control group pretest and posttest design was used to conduct qualitative coding and quantitative analysis on two classes in grade 5. The aim was to investigate whether science education videos can be used in place of simulation experiments. The results showed that (1) in terms of scientific knowledge, the difference between science videos and hands-on experiments was not significant; (2) in terms of modeling capability, the hands-on class had better results regarding the perception and application of materials; and (3) more precise experiments had better effects on health behavior, but there was no significant difference between imprecise experiments and science videos. In the absence of laboratory equipment, science videos could therefore be an alternative solution.

Keywords Science videos, Simulation experiments, Thinking-based inquiry teaching, Modeling ability

Introduction

Hands-on experiments play a core and particular role in science education (Hofstein & Lunetta, 2003). Experimental experience is believed to enhance students' understanding and application of scientific concepts, improve their practical scientific skills and problem-solving abilities, cultivate their scientific thinking habits, help them learn about scientific work methods, and enhance their interest and motivation in learning. In school science education, hands-on experiments hold a dominant position, and teachers' understanding of inquiry is often limited to hands-on experiments.

However, in the scientific reasoning style, experiments are only one of six parts (Kind & Osborne, 2017). Research showed that having students conduct virtual experiments and watch videos are equivalent to or better than having students do experiments themselves (Abdel-Salam et al., 2006; Brinson, 2015) and that video and animation can also achieve better teaching effects in science education (Harwood & McMahon, 1997), all of which indicate that hands-on experiments are not the only choice for science teaching.

In addition, some simulation experiments in primary school still have the problem of not being scientifically rigorous enough. Castillo et al. (2017) found that the beneficial effect of hands-on experimentation was either absent or in the wrong direction for adults. They suggested that hands-on experiences highlighted unnecessary aspects of the situation and masked relevant aspects, when it highlights irrelevant features it could backfire. Therefore, we imagine that instead of having students perform incorrect simulation experiments, it would be better to directly use science education videos to explain correct scientific knowledge to students.

Can science education videos replace hands-on experiments? We need to answer the following questions: (1) Is there no significant difference between science education videos and hands-on experiments in achieving teaching objectives? (2) What are the differences between the

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learning effects of science education videos and hands-on experiments? (3) Under what circumstances are science education videos a good alternative to hands-on experiments?

Why can science education videos be an alternative solution?

Why hands-on experimental?

Hands-on experiments, also known as traditional laboratory experiments, are a learning method in which students conduct on-site experiments using real equipment to obtain first-hand experimental data. Simulation experiments are also a common teaching method used to enhance teaching and education (Reynolds, 2008). In primary school science teaching in China, simulation is also regarded as a kind of hands-on experiment. The simulation is used to gather insight into the phenomenon or into simulation validity. For example, make a model of a flower or simulate the upper limb movement of the human body. It may be to gain further insight into the simulated phenomenon.

There are many purposes for using hands-on experimental learning in teaching. First, based on the theory of media richness, some researchers claim that when using real devices, students can obtain more information and discover more clues to explore (Schubert et al., 2001; Schuemie et al., 2001). Second, researchers also claim that traditional hands-on experiments can enable students to acquire complex scientific epistemology, understand imperfect measurement, and coordinate and explain the "unexpected conflict" between theory and experimental results (Magin & Kanapathipillai, 2000). In addition, hands-on experiments can cultivate the tactile information necessary for developing conceptual knowledge (Barsalou, 2008; Zacharia et al., 2012), allowing students to be exposed to specific images of objects and concepts mentioned in the classroom and linking specific observations with abstract representations and symbols (Priest et al., 2014). Finally, hands-on experiments can also enable students to acquire experimental skills, such as troubleshooting experiments, careful observation, organizing messy data, and experiencing real experimental time. Overall, researchers generally agree that hands-on experiments play four unique meaning construction roles in science classrooms: (a) enacting material interaction, (b) providing evidential meaning, (c) orientating three-dimensional spatial meaning and (d) sensitizing experiential meaning (Tang et al., 2022).

For all the benefits of hands-on experimentation, hands-on experiences doesn't have the same impact on students' science achievement. In fact, there is indeed evidence that hands-on activities help with learning (Castillo et al., 2017). Some studies have found that middle-school students who engaged in hands-on activities every day or once a week scored better science performance on a standardized test (Stohr-Hunt, 1996). However, other researchers have found that classes taught by either a hands-on or not method resulted in equal declarative knowledge achievement, but students in the hands-on laboratory class performed significantly better on the procedural knowledge test (Glasson, 1989). On the ability to design and interpret controlled experiments, researchers found no general advantage or disadvantage of hands-on experimentation on the control-of-variables-strategy and content knowledge tests (Schwichow et al., 2016). Research showed that virtual experiments and hands-on experiments are equally effective in developing students' conceptual, inquiry skills (Kapici, Akcay & Cakir, 2022), experimental skills (Akçayır et al., 2016; Sarı Ay & Yılmaz, 2015) and scientific attitude (Kapici et al., 2020). Different preferences for learning outcomes indicate that differences in the teaching objectives of experiments among science educators seem to be an important factor in the debate over the effectiveness of hands-on and other methods (Brinson, 2015).

Why video could be?

"Video is a valuable teaching tool because it can be used to show students things that would be otherwise hard to organize 'live'" (Pasquali, 2007): This statement suggests that the use of videos in teaching is not new. However, teachers long used videos only for noneducational purposes, such as passing time, keeping students quiet, entertaining, motivating students, etc. (Hobbs, 2006). With the development of technology, people are increasingly paying attention to using videos as an indispensable teaching tool for courses to teach school science (Berk, 2009; Everhart, 2009). Researchers believe that science videos are often effective teaching tools that can bring abstract and distant science into students' world of meaning (Harwood & McMahon, 1997). The structure and organizational form of video content can guide students' attention and knowledge construction direction, attracting learners' attention to the right place at the right time (Berney & Bétrancourt, 2016; Rosenthal, 2020) and making students shift toward higher levels of participation, involving principles, calculations, and experimental design, rather than experimental troubleshooting. Students are more inclined to ask and solve problems (Croker et al., 2010) instead of seeking operational guidance, develop an understanding of scientific evidence and have the opportunity to discuss in groups (Bennett et al., 2009). Videos dynamically provide information in auditory and visual channels, clearly describing situational dynamics, and may help learners establish coherent, high-quality mental models of complex change processes, which have been proven to effectively support learning (Berney & Bétrancourt, 2016; Merkt et al., 2018).

As the utilization of instructional videos for science teaching has become more widespread, researchers argue that there is potential for using such videos for instruction in science and the nature of science (Park et al., 2022; Poor et al., 2023). Video animations are particularly well suited for illustrating abstract or hard-to-visualize phenomena relevant to health science, such as neuroanatomy and brain functions; watching videos to engage in evidence-based health education therefore has the capacity to positively impact young people's experiences of health (Pate et al., 2020). The use of teaching anatomy videos in medical schools has also improved students' anatomical achievements (Saxena et al., 2008). Research shows that science education videos can foster conceptual learning and application. Ramachandran et al. (2019) find that watching videos significantly improves student learning and reinforces conceptual understanding of important foundational concepts. Mutch-Jones et al. (2020) also demonstrated that students who watch videos perform significantly better on exam scores for scientific concepts and techniques. They thus conclude that professional instructional videos have the potential to significantly improve students' performance. Some studies also show that video-worked examples can promote elementary students' science processing skills (Solé-Llussà et al., 2019, 2020). The results of Solé-Llussà et al. (2019, 2020), for example, suggest that video-worked examples have a positive influence on students' inquiry skills such as controlling variables; identifying research questions; collecting, organizing and representing data; analyzing data and drawing conclusions; interpreting results; and enhancing the quality of their scientific investigations and models.

From the perspective of efficiency, focus, and excitement, science education videos and virtual experiments can thus be used in place of hands-on experiments. Kind and Osborne (2017) believe that if the role of teachers is to help students learn scientific thinking and understand how scientific knowledge is generated, then performing science is just one of the teaching methods, similar to teaching, writing, and reading science. Teachers can use various teaching methods, depending on what they want their students to learn. For the same teaching objectives, hands-on experiments, virtual experiments, and science education videos are only one of the possible alternative solutions. In terms of current development speed, establishing virtual laboratories is still a potentially more expensive solution for most schools in China than traditional laboratories. Some scientific ideas cannot be obtained in school laboratories or through on-site learning, and using edited videos for teaching can expand students' learning resources (Higgins et al., 2018).

Accordingly, science education videos have the potential to be an alternative to hands-on experiments. Science education videos even have advantages in teaching over hands-on experiments and can achieve good learning outcomes with appropriate instructional design. In this study, the science education videos we evaluated use animation to explain scientific concepts and principles; they do not explain experimental steps and methods present virtual experiments. This study also defines hands-on experiments as "using materials to make a model to simulate body movement and heart work." Nor were the focal science education videos were made available to students in advance, as in flipped classrooms. Instead, the students viewed the videos and discussed them in class according to the needs of scientific argumentation.

Methods

Participants and context

In China, the science curriculum standards specify what content and competences should be taught to the students in the primary school science curriculum. Textbook writers will develop the course content and teaching process that can meet the requirements of the curriculum standards. Teachers should compare the curriculum standards and textbooks in teaching and combine the actual situation of the students they face, deciding to adopt the process of the textbook or adapt the textbook to suit the students. Therefore, based on the content of these two lessons, our study also determined the teaching objectives that can be achieved by simulating experiments in these two classes according to the course standard and the teacher's guide accompanying the textbook, and combined with the target selection of experienced teachers who have attended these two classes. Our hypothesis was that if teachers could achieve the same teaching goals as they could with a simulation experiment, then video was a good alternative.

Almost all primary school science teachers rely too much on textbooks when teaching, and they usually strictly follow the design thereof. They believe that textbooks are correct and fundamentally authoritative and that final exams strictly test the content and experiments in such textbooks. Although national quality monitoring emphasizes the assessment of students' key scientific competence, teachers are still concerned that teaching scientific literacy in accordance with students' true ideas may prevent them from passing their local final exams. Therefore, sometimes even if teachers know that the teaching steps in textbooks do not effectively promote students' scientific literacy or that the simulation experiments in these textbooks are not sufficiently rigorous, they rarely change their teaching process and materials. To prove to teachers that if their teaching process is changed and no rigorous simulation experiments are conducted, these will not have a significant impact on their students' grades, we conducted this study, replacing the conducting of simulation experiments with watching science education videos. Accordingly, we adopted local test questions to verify that students' grades would not decrease and used scientific literacy test questions to verify that students' literacy would not be decreased.

Two fifth-grade classes were selected from ordinary urban primary schools. These two classes were randomly assigned 101 students. Among them, there were 54 male students and 47 female students. One class adopted the teaching method of simulation experiments, with 26 boys and 24 girls among the 50 students. The other class watched science popularization videos for discussion, with 28 boys and 23 girls among the 51 students. Both classes were taught by the same science teacher with 15 years of experience in science teaching. This teacher has the spirit of innovation and reform, and she is familiar with and accustomed to using thinking-based inquiry teaching theory in her teaching design. Therefore, this teacher used materials from textbooks but changed her teaching process. Moreover, this study only compared whether students' learning effect was different when watching science education videos or performing simulation experiments amid the same thinking-based inquiry teaching.

Design and materials

This study was designed for the experimental group and the control group. The independent variable is different teaching methods (hands-on simulation experiment-assisted teaching and teaching assisted by popular science videos), and the dependent variable is the learning effect. The learning effect is measured by test scores after class. We did a pre-test and post-test before and after class, and a migration test a week later.

Hands-on simulation experiments and video materials

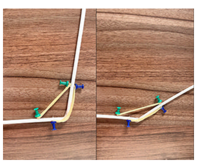
The content of the two classes is "Body Movement" and "Heart and Blood". The movement of the body mainly involves lifting dumbbells with the upper limbs as an example to help students understand how bones, joints, and muscles work together to complete the movement. The hands-on simulation experiment follows textbook settings, using chopsticks, rubber bands, and strings to simulate the process of bone, joint, and muscle coordination. "Heart and Blood" mainly discusses "What is heart beating", "what is the force that pushes the blood through blood vessels" and "how to protect the heart". The hands-on simulation experiment is consistent with the textbook. Materials such as ear suction balls, hoses and sinks are used to simulate the relationship between the heart and blood. In teaching, it is found that the working mechanism of the heart in the ear-sucking ball experiment, in which water is sucked in and squeezed out by the hand ball, is not consistent with the real cardiopulmonary circulation mechanism. One class carried out the normal simulation experiment according to the content of the textbook. In the other class, we replaced the simulation experiment with a correct popular science video, which was played for the students to discuss and mention. Other teaching links remained basically unchanged. The videos are popular science videos searched for and downloaded by teachers on the internet with the intention of using them in teaching and edited according to teaching needs, including "bone joint movement", "muscle movement", "heart structure and function", "heart and pulse", and "human blood circulation". Tables 1 and 2 show the specific content of each of the three implementation examples.

Evaluation tools

Existing research on teaching by traditional hands-on experiments or videos has shown that experiments or multimedia teaching, such as videos and animations, do not always have significant advantages. The effectiveness of experiments or video instruction is also related to learning outcome preference (Brinson, 2015). In other words, the effectiveness of teaching methods may vary depending on the teaching objectives of specific teaching content. Therefore, in response to the teaching content of the two lessons in this study, we studied curriculum standards, textbooks, and teacher reference books and conducted interviews with 17 science teachers from different schools and teaching years. The interview question was "What do you think the teaching objectives of the simulation experiment in the textbook are?" Finally, the teaching objectives of the simulation experiments in the two lessons were determined to be mainly knowledge objectives, modeling ability, and body protection (See Appendix for details). If the use of popular science video teaching can also achieve the teaching objectives as simulation experiments, video learning can be considered an alternative to hands-on experiments. Therefore, based on the teaching objectives of the simulation experiment in these two lessons, we designed pre- and posttest questions and maintenance test questions.

The pre- and posttest questions were developed according to the teaching content. Considering that the pre- and post- tests were administered immediately before and after class in 3 min intervals, we chose to use objective questions for measurement. Because the questions related to scientific attitude were not suitable for the objective tests, the three minutes before and after class were not used to test students' health awareness. There were four single-choice questions in the pre- and posttest questions of the "Body Movement" lesson. The first two questions examined the conceptual understanding of this

Table 1 Classroom implementation of "Body Movement"

Example	Content
Textbook 	1. Focus: How do bones, joints and muscles move? How can we protect them and promote their growth? 2. Explore: Lift dumbbells, observe and feel the changes in different parts of the upper limb. Using the materials provided, make a motion model of the forearm raised. Think about which parts of the model correspond to bones, joints, and muscles. Protect the motor organs. 3. Discussion: Describe how bones, joints and muscles work together to lift a dumbbell. What should we do to promote bone and muscle development? 4. Extension: What are some of the objects in our lives that in some way act like the bones, joints, or muscles in our bodies?
Simulation experimentation 	1. Motivation: When lifting dumbbells, which major organs in the arm are involved in the movement? How do bones, joints, and muscles change to perform arm flexion and arm extension? 2. Cognitive conflict: Based on the experience of lifting dumbbells, draw and exchange the motion model diagram of bending and extending arms and discuss which model is more explanatory. 3. Self-construction: Use the materials provided by the teacher to make a motion model, think about which part of the model is equivalent to bone, joint and muscle, and understand and verify the motion model of bone, joint and muscle during arm flexion and extension through simulation experiments. 4. Self-monitoring: Describe how bones, joints and muscles work together to lift a dumbbell. What should we do to promote bone and muscle development? 5. Application transfer: What are some of the objects in our lives that in some way act like bones, joints, or muscles in our bodies?
Science education video 	1. Motivation: When lifting dumbbells, which major organs in the arm are involved in the movement? How do bones, joints, and muscles change to make arm flexion and arm extension? 2. Cognitive conflict: Based on the experience of lifting dumbbells, draw and exchange the motion model diagram of bending and extending arms and discuss which model is more explanatory. 3. Self-construction: Using the pictures in the provided material, students think about and discuss how to design simulation experiments to provide their own views; what is simulated in each part? Students watch scientific education videos to understand the movement of bones, joints and muscles inside the arm, and to construct the concept of the synergy of bones, joints and muscles; Students watch videos of the process of repairing a broken arm to build an awareness of healthy living. 4. Self-monitoring: Describe how bones, joints and muscles work together to lift a dumbbell. What should we do to promote bone and muscle development? 5. Application transfer: What are some of the objects in our lives that in some way act like bones, joints, or muscles in our bodies?

lesson, and the last two questions examined the ability to construct models. There were 6 questions before and after the "Heart and Blood" lesson, of which 5 tested concept understanding and application and 1 tested modeling ability. Examples are shown in Table 3. Students were not told during the pre-test or during the instruction that there would be a post-test at the end of the class.

Because the objective tests make it difficult to measure whether the students got the right answers because they had retained knowledge or because they had mastered the science competences, we designed an open-ended questionnaire to be tested a week later. This questionnaire is designed to test whether students are able to use scientific knowledge or scientific competences to explain scientific processes or solve scientific problems in new situations. The first "Body Movement" question asked students to use words or pictures to describe how to simulate the movement of the knee, and the second question asked students to describe how the knee performs when completing a squat and stand up. The third question asked students to report how to protect the joints throughout life. According to the students' performance, in the first question, their answers were divided into 4 performance levels; in the second question, they were divided into 5 performance levels; and the third question yielded extra points according to the students' correct answers. In the open question of the lesson "Heart and Blood", the first question used the measuring tool of Ozgur (2013), asking students to write or draw their knowledge of the heart and blood circulation, and the second question asked students how to protect their heart. Students' answers to the first question were divided into four performance levels, and the second question yielded extra points according to the category of students' correct answers. Below, Table 4 lists specific test questions and grading standards.

Table 2 Classroom implementation of "Body Movement": "Heart and Blood"

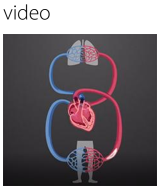
Example	Content
Textbook 	1. Focus: Our heart is beating all the time; what is the meaning of its beating? 2. Explore: Use a suction ball to repeatedly suck in and out water. How does your hand feel after a minute? How many times can we squeeze it in a minute? Compare the time needed to restore the normal heartbeat after jumping for one minute with the students who love sports. Reasonable rest and good sleep will make the heart work better, which is conducive to our health. 3. Discussion: What is the significance of the heart's beating? What forces push blood through the veins? Does the heart get tired? How do we protect our hearts? 4. Extension: Measure your heart rate and pulse. What did you find from the data?
Simulation experimentation 	1. Motivation: Our heart is beating all the time; what is the meaning of its beating? Measure your heart rate and pulse. What did you find from the data? What does the heart have to do with blood? What forces push blood through the veins? 2. Cognitive conflict: How does blood circulate in the body through the heart? When the heart contracts, does blood flow out of the heart or back? Does blood flow out of the heart or back to the heart when the heart diastoles? 3. Self-construction: Students perform a simulation experiment using the suction ball to repeatedly suck in and out water, thinking about what was simulated in the experiment by pinching and loosening the suction ball. How is this experiment the same and different from the real heart's pumping of blood? How does your hand feel after a minute? What is the significance of the heart's beating? Compare the time needed to restore your normal heartbeat after jumping for one minute to that of students who love sports. 4. Self-monitoring: What forces drive blood flow through the blood vessels? How could the simulation be improved? 5. Application transfer: How can we protect our hearts?
Science education video 	1. Motivation: Our heart is beating all the time; what is the meaning of its beating? Measure your heart rate and pulse. What did you find from the data? What does the heart have to do with blood? Students watch videos to learn about the structure and function of the heart and think about what forces push the blood through their veins. 2. Cognitive conflict: How does blood circulate in the body through the heart? When the heart contracts, does blood flow out of the heart or back? Does blood flow out of the heart or back to the heart when the heart diastoles? 3. Self-construction: Students watch science education videos to understand blood circulation in the human body (cardiopulmonary double circulation) and understand the meaning of a heartbeat. Compare the time needed to restore your normal heartbeat after jumping for one minute with that of students who love sports. 4. Self-monitoring: What forces drive blood flow through the blood vessels? 5. Application transfer: How can we protect our hearts?

Table 3 Sample multiple choice question on scientific concept and modeling capability

Example	"Body Movement" lesson	"Heart and Blood" lesson	
Scientific concept	The main function of muscles in the human body is ( )	When calm, the average person's heart rate is about ( ) beats per minute?	
	A. Protect the human body	A. 30–50	B. 60–100
	B. Exercise		
	C. Contraction and diastole	C. 120–150	D. 150–180
	D. Support human body		
Modeling capability	When making your own motion model, you can use ( ) to simulate joints?	When performing experiments to simulate the workings of the heart, the action of repeatedly squeezing the suction ball simulates ( )	
	A. Small wooden stick	A. Blood flow	B. Chest movement
	B. Rubber band		
	C. Plastic bend	C. Heart beating	D. Lung breathing
	D. Balloon skin		

Interrater reliability

The measuring tools were evaluated by two raters who took 25% of all questionnaires first. The first rater is the first author of this paper. She is a doctor of science education who has been trained specifically in educational science research methods and has rich experience in coding analysis. The second coder is the second author of this paper and the science teacher involved in the teaching intervention experiment in this study. She has 15 years of science teaching experience, has conducted coding work for many studies together with the first author, and has received professional coding training. After agreeing on the scoring standard, the consistency coefficient kappa of the raters was found to be above 0.772 (Table 5). "For most purposes, values greater than 0.75 or so may be taken to represent excellent agreement beyond chance, values below 0.40 or so may be taken to represent poor agreement beyond chance, and values between 0.40 and 0.75 may be taken to represent fair to good agreement beyond chance" (Banerjee et al., 1999). Therefore, the coefficient kappa in our study

Table 4 Open questions and grading criteria

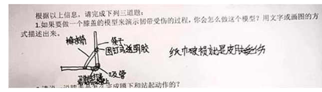
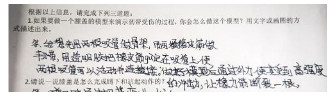
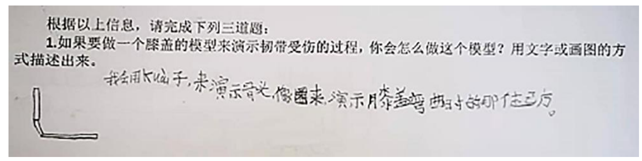
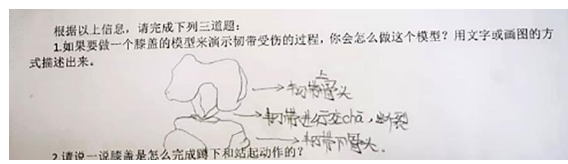
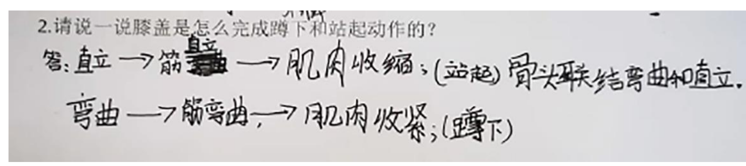
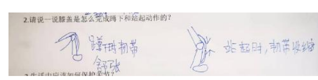
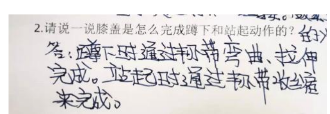
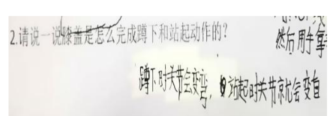
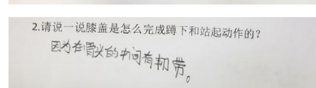
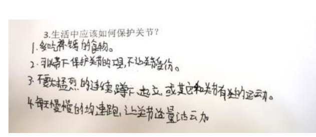
Question	Level	Example
If you were to make a model of the knee to demonstrate the process of ligament injury, how would you make this model? Describe it in words or pictures.	Level 3: Material selection was reasonable, simulation was correct, and there was some innovation.	
	Level 2: Material selection was reasonable and the simulation was basically correct.	
	Level 1: Material selection was reasonable, but the injury process was not simulated or the simulation was wrong. Or, the material selection was partly reasonable, but the simulation was basically correct.	 根据以上信息，请完成下列三道题： 1.如果要做一个膝盖的模型来演示韧带受伤的过程，你会怎么做这个模型？用文字或画图的方式描述出来。
	Level 0: Reiterated the process given in the situation, but the responder had no awareness of simulation. No field or incorrect field.	 根据以上信息，请完成下列三道题： 1.如果要做一个膝盖的模型来演示韧带受伤的过程，你会怎么做这个模型？用文字或画图的方式描述出来。
How does the knee work when squatting and standing up?	Level 4: The work and function of each structure while crouching and standing were described.	 2.请说一说膝盖是怎么完成蹲下和站起动作的？ 答：直立 → 筋 → 肌肉收缩；(站起) 骨头联结弯曲和直立。 弯曲 → 筋弯曲 → 肌肉收紧；(蹲下)
	Level 3: Students knew the work and function of several constructions but only described the movements of squatting or standing up. Or, both crouching and standing up were described but only with one construct.	
	Level 2: Knew the work and function of a construct, or knew that coordination was needed to accomplish an action.	 2.请说一说膝盖是怎么完成蹲下和站起动作的？ 答：蹲下时通过韧带弯曲、拉伸完成。站起时通过韧带收缩来完成。
	Level 1: Knew the different motion states of crouching and standing but did not explain them.	 2.请说一说膝盖是怎么完成蹲下和站起动作的？
	Level 0: Answered phenomena with phenomena, without mentioning processes and principles. Or, the answer was wrong, etc.	 2.请说一说膝盖是怎么完成蹲下和站起动作的？
How do we protect our joints in life?	Do not overexert, soothing protection, exercise fitness, nutritious diet, etc., mentioned 1 category score 1.	 3.生活中应该如何保护关节？

Table 4 (continued)

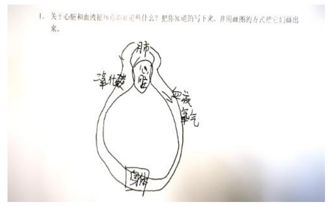
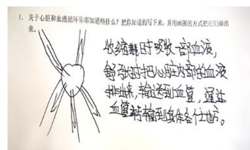
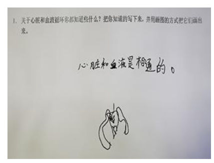
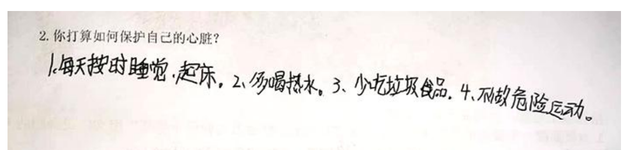
Question	Level	Example
What do you know about the heart and blood circulation?	Level 3: Knew the function and circulation of the heart and blood.	
	Level 2: Knew the connection between the heart and blood but was unclear or wrong about the circulation process.	
	Level 1: Knew the work of the heart and blood but did not know the connection between them. Or, knew the connection between them but did not know how the heart or blood work.	
	Level 0: Did not answer the question, etc.	
How do you protect your heart?	Regular work and rest, healthy diet, exercise, etc.; receive 1 point for correct answers.	

Table 5 Consistency coefficient of scorers for the top 25% of questionnaires

Question number	1.1	1.2	1.3	2.1	2.2
Kappa	0.943	0.772	0.801	1.000	1.000

was acceptable. After further discussion, the grading criteria were revised again, and the remaining papers were scored separately.

Results

All data were analyzed and processed using SPSS 21.0. Since there were significant differences in modeling ability between the hands-on class and the video-watching class in the pre-test on the body lesson, we used repeated-measures analyses of variance (ANOVAs) to analyze whether there were significant differences in scientific concepts and modeling ability between these two groups before and after class. Because the test administered one week later was different from the pre-test and post-test questions, we used covariance analysis to analyze whether there were significant differences in scientific concepts, modeling ability and health awareness between the two classes one week later.

General analysis

The participants were fifth grade primary school students, and the descriptive statistics are shown in Table 6. In the "Body Movement" lesson, 50 people in the hands-on class participated in the pre- and post- tests. The class that watched the video had 51 participants in the pre- and post- tests. In the "Heart and Blood" lesson, since 2 people in the hands-on class were late, 48 people participated in the pre-test and 50 in the post-test. Three students in the class who watched the video did not attend class, and only 48 people participated in both the pre- and post- tests. A week later, in the open question test on the two lessons, 48 people took the test in the hands-on class, and 44 people took the test in the class that watched the video. The results showed that after the "Body Movement" Lesson and the "Heart and Blood" Lesson, both the hands-on class and the class that watched the video improved their grades, and the hands-on class improved more. But whether the difference was significant needs to be further tested.

Table 6 An overview of student test results

	Group	Participant (n)	Average (M)	Standard deviation (SD)
Concept score of lesson 1 pretest	Hands-on group	50	0.620	0.697
	Video group	51	0.706	0.642
Modeling score of lesson 1 pretest	Hands-on group	50	1.120	0.872
	Video group	51	1.510	0.703
Concept score of lesson 1 posttest	Hands-on group	50	1.080	0.566
	Video Group	51	1.078	0.627
Modeling score of lesson 1 posttest	Hands-on group	50	1.640	0.563
	Video group	51	1.373	0.692
Modeling score of lesson 1 open question	Hands-on group	48	2.146	0.922
	Video group	44	2.091	1.217
Concept score of lesson 1 open question	Hands-on group	48	1.438	0.848
	Video group	44	1.523	0.849
Body protection score of lesson 1 open question	Hands-on group	48	1.646	0.758
	Video group	44	1.205	0.553
Concept score of lesson 2 pretest	Hands-on group	48	2.833	1.155
	Video group	48	3.229	0.973
Modeling score of lesson 2 pretest	Hands-on group	48	0.521	0.505
	Video group	48	0.521	0.505
Concept score of lesson 2 posttest	Hands-on group	50	4.180	0.896
	Video group	48	3.9167	0.739
Modeling score of lesson 2 posttest	Hands-on group	50	0.840	0.370
	Video group	48	0.708	0.459
Concept score of lesson 2 open question	Hands-on group	48	1.229	0.778
	Video group	44	1.386	0.689
Body protection score of lesson 2 open question	Hands-on group	48	1.563	0.966
	Video group	44	1.523	0.902

Teaching effectiveness analysis

We took the scientific concept and modeling ability scores in the single-choice pre- and posttest of "Body Movement" and "Heart and Blood" as dependent variables for repeated analysis of measurement variance (ANOVAs).

The results showed that the main effect of time on the achievement of scientific concepts in "Body Movement" was significant ($F = 27.790$, $p < 0.001$, $\eta^2 = 0.219$), indicating significant differences in scientific concept scores at different time points. The interaction between time and group was not significant ($F = 0.307$, $p = 0.581$, $\eta^2 = 0.003$), indicating that there was no significant difference between the two groups at different time points. In the simple effect analysis, the group dimension results showed that the scores of the hands-on group ($F = 16.801$, $p < 0.001$, $\eta^2 = 0.145$; $M_{\text{before}} = 0.620$, $M_{\text{after}} = 1.080$) and watching video group ($F = 11.241$, $p = 0.001$, $\eta^2 = 0.102$; $M_{\text{before}} = 0.706$, $M_{\text{after}} = 1.078$) both significantly improved after receiving teaching. In terms of the time dimension, there was no significant difference between the two groups in the scores of the pre- and posttests ($F_{\text{before}} = 0.416$, $p_{\text{before}} = 0.521$, $\eta^2_{\text{before}} = 0.004$; $F_{\text{after}} = 0.000$, $p_{\text{after}} = 0.990$, $\eta^2_{\text{after}} = 0.000$). This indicates that both the simulation experiment and the science video significantly improved students' scientific concept achievement, and there was no significant difference between the simulation experiment teaching and watching science video teaching effect.

The main effect of time on modeling performance in the "body movement" lesson was significant ($F = 5.049$, $p = 0.027$, $\eta^2 = 0.049$), indicating that differences in modeling performance at different time points were significant. The interaction between time and group was significant ($F = 14.889$, $p < 0.001$, $\eta^2 = 0.131$), indicating significant differences between the two groups at different time points. In the simple effect analysis, the results of the group dimension showed that the hands-on experimental group ($F = 18.457$, $p < 0.001$, $\eta^2 = 0.157$; $M_{\text{before}} = 1.120$, $M_{\text{after}} = 1.640$) significantly improved in their modeling scores after receiving teaching, while the video watching group ($F = 1.312$, $p = 0.255$, $\eta^2 = 0.013$; $M_{\text{before}} = 1.510$, $M_{\text{after}} = 1.373$) showed a decrease in modeling scores after teaching, but this difference was not significant. Concerning the group that watched the video, although no statistically significant differences were observed between the pre- and post- test on the modeling factors, the post-test trended toward a less negative gain in modeling ability. In terms of the time dimension, there was a significant difference in the pre- and posttest scores between the two groups (F_{before} = 6.123, p_{before} = 0.015, η^2_{before} = 0.058; F_{after} = 4.533, p_{after} = 0.036, η^2_{after} = 0.044). This indicates that before teaching, the modeling ability of the video class was significantly higher than that of the hands-on experimental class. After the teaching interventions, the modeling ability of the video class decreased, while the modeling ability of the hands-on experimental class improved. The modeling ability of the video class was significantly lower than that of the hands-on experimental class. This may be related to the fact that the test questions are about the classroom teaching content (Table 3). The class watching the video constructed the scheme design of the simulation experiment according to the given material in class. They provided three feasible schemes in total, but they had no chance to verify whether various materials could realize the functions in their schemes. The hands-on class decided on a common and unique simulation scheme after the whole class participated in collective discussion, that is, the correct simulation scheme in the textbook and test questions. Therefore, the class with the hands-on experiment had a clearer answer to this question after class, while the class watching the video was more uncertain than they were before class because of the existence of three possibilities.

For the scientific concept scores in the "Heart and Blood" lesson, the main effect of time was significant (F = 86.119, p < 0.001, η^2 = 0.478), indicating significant differences in scientific concepts at different time points. The interaction between time and group was significant (F = 8.796, p = 0.004, η^2 = 0.086), indicating significant differences between the two groups at different time points. In the simple effect analysis, the results of the group dimension showed that the hands-on experimental group (F = 74.980, p < 0.001, η^2 = 0.444; M_{before} = 2.833, M_{after} = 4.167) and video watching group (F = 19.935, p < 0.001, η^2 = 0.175; M_{before} = 3.229, M_{after} = 3.917) both improved significantly in scientific concept scores after receiving instruction, and the hands-on experiment group increased more. In the time dimension, the difference between the concept scores of the two groups was not significant (F_{before} = 3.299, p_{before} = 0.073, η^2_{before} = 0.034; F_{after} = 2.192, p_{after} = 0.142, η^2_{after} = 0.023). This indicates that both teaching through simulation experiments and using science videos for learning can significantly improve students' scientific concept achievement. The improvement in science concept scores was greater in the class that used hands-on experiments.

The main effect of time was significant in the modeling score of the "Heart and Blood" lesson (F = 23.557, p < 0.001, η^2 = 0.200), indicating significant differences in modeling performance at different time points. The interaction between time and group was not significant (F = 1.847, p = 0.177, η^2 = 0.019), indicating that there was no significant difference between the two groups at different time points. In the simple effect analysis, the results of the group dimension showed that the hands-on experimental group (F = 19.298, p < 0.001, η^2 = 0.170; M_{before} = 0.521, M_{after} = 0.854) and video watching group (F = 6.106, p = 0.015, η^2 = 0.061; M_{before} = 0.521, M_{after} = 0.708) both showed significant improvement in modeling scores after receiving instruction. In terms of the time dimension, the modeling scores of the pre- and posttest between the two groups were not significantly different (F_{before} = 0.000, p_{before} = 1.000, η^2_{before} = 0.000; F_{after} = 3.018, p_{after} = 0.086, η^2_{after} = 0.031). This indicates that both using simulation experimental teaching methods and using science videos for learning can significantly improve students' modeling ability. There is no significant difference between the effectiveness of simulation experiment teaching and watching science video teaching.

According to the immediate feedback, both hands-on experiments and video teaching can improve students' achievement in science concepts. The impact of hands-on experiments on modeling ability in the "Body Movement" lesson was significantly better than that of the popular science videos, while there was no significant difference in the "Heart and Blood" lesson (Table 7).

Analysis of the delayed effect

One week after the completion of the two teaching sections, we used open-ended questions to assess students'

Table 7 Results of pre- and post-test statistical analysis

Comparative items		**"Body Movement" lesson**		**"Heart and Blood" lesson**	
		Science concept	**Modeling ability**	**Science concept**	**Modeling ability**
Improvement/decline after teaching intervention	Video group	Significant improvement	No significant decline	Significant improvement	Significant improvement
	Hands-on group	Significant improvement	Significant improvement	Significant improvement	Significant improvement
Comparison of differences between groups	Pretest	No significant difference	The video group scored significantly higher than the hands-on group	No significant difference	No significant difference
	Post-test	No significant difference	The video group scored significantly lower than the hands-on group	No significant difference	No significant difference

literacy. In data analysis, analysis of covariance analysis was conducted with the scores of open questions as the dependent variable and the scores of the pretest as the covariate. As a result, the following was found:

The group main effect of the scientific concept score of "body movement" was not significant ($F = 0.173$, $p = 0.678$, $\eta^2 = 0.002$), and the group main effect of modeling was not significant ($F = 0.125$, $p = 0.725$, $\eta^2 = 0.001$). In the "Heart and Blood" lesson, the main effect of the scientific concept scores was also not significant ($F = 0.712$, $p = 0.401$, $\eta^2 = 0.008$). The total score of the previous test was a covariate, and in the "Body Movement" lesson, the hands-on experimental group scored significantly better than the video watching group in terms of health awareness ($F = 8.855$, $p = 0.004$, $\eta^2 = 0.090$, $M_{\text{experiment}} = 1.637$, $M_{\text{video}} = 1.214$). In the "Heart and Blood" lesson, the main effect of group was not significant ($F = 0.170$, $p = 0.681$, $\eta^2 = 0.002$, $M_{\text{experiment}} = 1.592$, $M_{\text{video}} = 1.507$). A results summary is provided in Table 8.

In the time-delay measurement, there was no significant difference in scientific concept and modeling ability between the hands-on experiment group and the video watching group. However, in terms of health awareness, the hands-on experiment class scored significantly better than the video-watching class in the "Body Movement" lesson, and there was no significant difference in health awareness in the "Heart and Blood" lesson. This may be related to the precision of the simulation experiments. The simulation experiment of the "Body Movement" lesson is more scientific, but the simulation experiment of the "Heart and Blood" lesson is imprecise with regard to double cardiopulmonary circulation, as the simulation activity can only partially simulate the mechanism/process. Hence, more scientific simulation experiments provide better development in their modeling and mechanism and play a stronger role in promoting students' health awareness. However, less rigorous simulation experiments have difficulty improving the understanding of mechanisms and thus affect both health awareness levels and life decisions.

Discussion

With the increasing use of computer-assisted instruction in classroom teaching, the core position of hands-on experiments in science education is constantly being challenged. An increasing number of researchers have discussed the feasibility of replacing hands-on experiments from different perspectives. Replacing hands-on experiments with more accessible science education videos is a possible solution. This study has investigated the teaching effectiveness of replacing hands-on experiments with science education videos.

In previous studies, due to the different preferences of researchers for results and the focus of measurement, the research conclusions obtained were inconsistent (Brinson, 2015). This study identified the main teaching objectives for the two lessons by analyzing curriculum standards, textbooks, teaching reference books, and consulting science teachers at different levels. Based on the consensus of goals, test questions were developed to measure scientific concepts, modeling ability, and health awareness, ensuring the universality and guidance of expected results.

We wanted to address the following question: "Can science education videos replace hands-on experiments?" If watching science education videos could achieve the same expected learning results as hands-on experiments, less costly and time-saving science education videos could be considered equivalent to hands-on experiments in terms of learning results, whereby the former can be used as an alternative to hands-on experiments.

Impact on scientific concept achievement

In this study, two science lessons focused on the field of life sciences, both involving simulation experiments. Our results showed that both hands-on experiments and video watching could improve students' achievement in science concepts. This conclusion was consistent with previous studies that emphasized hands-on experiments (Abit et al., 2018; Stohr-Hunt, 1996) and watching science education videos (Berney & Bétrancourt, 2016).Because reasoning development is in part dependent upon physical experience (Kwon et al., 2000), and animations can convey the configuration of a system, system dynamics and the causal chain underlying the functioning of dynamic systems (Berney & Bétrancourt, 2016).

In addition, the results showed that there was no significant difference in the scores of scientific concepts between the hands-on experiments and the video watching classes. This was not consistent with the research findings of the Colorado Department of Higher Education (Colorado DOHE, 2012).

Table 8 Results of delayed effect statistical analysis

Comparative items	"Body Movement" lesson			"Heart and Blood" lesson	
	Science concept	Modeling ability	Healthy	Science concept	Healthy
Comparison of differences between groups	No significant difference	No significant difference	The video group scored significantly lower than the hands-on group	No significant difference	No significant difference

The reason why hands-on experimental class had no significant advantage in conceptual understanding of our research might be related to our instructional design. Researchers have claimed that effective multimedia in teaching should be used to encourage thinking, multimedia should be matched with teaching objectives, and scientific processes that require high-quality explanations and are unlikely to be replicated in the classroom environment are preferred (Higgins et al., 2018). Researchers generally claim that the use of multimedia, such as animation and video, is not a panacea in itself, whereby instructional design based on learning theory is needed to make it effective (Höffler & Leutner, 2007). Different from those in previous studies that have used video to attract attention, entertain and motivate students (Hobbs, 2006) rather than explaining scientific knowledge, in this study, both the hands-on experiment class and the video watching class adopted thinking teaching. In these two lessons, the teacher used thinking-based inquiry teaching, which first triggered cognitive conflicts among students then required them to perform simulation experiments or watch videos with questions and, finally, actively construct concepts and reflect on how to protect body organs (Table 1). Whether conducting experiments or watching videos, there was only one way students could obtain evidence when solving problems, and it was not a unique choice. Hands-on experiment and watching video were not the purpose but the carrier to encourage and assist students in thinking and promoting their participation in scientific arguments. Before performing experiments or watching science videos, students were guided to think about and explore questions first. Both simulation experiments and videos provided clues and evidence for students' thinking, and students would carry out classroom arguments according to the evidence obtained from the experiments or videos.

This study ensured, first, that the role of science videos in teaching design was to encourage thinking, and second, that the clips were closely related to the teaching content to effectively help students focus on exploring problems and supporting scientific arguments. At the same time, video content is a dynamic mechanism of interpretation, which is difficult to reproduce through static data and traditional hands-on experiments, so it could effectively compensate for this defect when learning the human body. Frederick (2013) argued that the definition of "hands-on" is no longer limited to students' access to and use of physical materials but emphasizes their mental "concentration" in engaging with the scientific topic they are learning. Therefore, we found that when students' attention was focused on understanding and arguing about scientific mechanisms, there was no significant difference in how students constructed scientific understanding, whether they manipulated experimental materials with their hands or watched and learned through science videos. For teachers' teaching, the quality of science videos might therefore be a more important problem that needs to be solved.

Impact on modeling ability

In our study, after the teaching interventions of the "Body Movement" lesson, among the class that watched the video, although no statistically significant differences were observed between pre- and post- test on the modeling factors, the post-test trended toward a less negative gain in ability. However, the class that performed hands-on experiments showed a significant improvement. After the teaching intervention, the modeling ability of the video class was thus significantly lower than that of the hands-on experimental class. This immediate improvement in modeling ability indicated the advantage of hands-on experiments for primary school students.

This result was consistent with existing research. Research suggested that elementary school students need to learn with objects, and personal experience helps students understand complex scientific mechanisms (Kontra et al., 2015). Zacharia et al. (2012) found that kindergarten students learning concepts related to beam balance showed that the existence of physical objects is not a necessary condition for understanding the concept but that students with incorrect prior knowledge of the function need to perceive its physicality. For students with poor prior knowledge, the simulation of abstract concepts increases the concept learning of less complex mechanisms, while for students with higher prior knowledge, it could simulate more complex potential mechanisms. That is, students learning complex scientific mechanisms require explicit representations of abstract objects in their learning environment (Olympiou et al., 2013). In our study, this was directly reflected in how the students who had a specific perception of the material were better able to judge which material was more suitable for simulation and were more likely to answer test questions correctly.

However, our study also found that in the "Heart and Blood" lesson, although the modeling ability of both classes improved significantly after teaching intervention, there was no significant difference between the two groups (Table 7). In other words, in the "Heart and Blood" lesson, the hands-on class did not have a significant advantage in modeling ability. This might be related to the preciseness of the simulated experiments in the two lessons. In the "Body Movement" lesson, using wooden chopsticks, rubber bands, and strings to simulate human upper limb movements was not sufficiently rigorous, but it could still be used to easily explain the mechanism of arm movement. However, in the "Heart and Blood" lesson, the device that compressed the rubber pipette bulb to absorb and drain water could only partially simulate the mechanism/ process of blood circulation. It can be considered that if the simulation experiment is more accurate, the hands-on experience could improve students' modeling ability; if the simulation experiment is not rigorous enough, the hands-on experiment has no obvious effect on the improvement of students' modeling ability.

Meanwhile, our study also found no significant difference in modeling ability between the two groups in the near transfer measurement after one week. This might mean that the improvement effect of hands-on experiments on modeling ability exists only when reviewing the simulation experiment itself and that the improvement in modeling ability is a long-term and lengthy process of literacy accumulation.

We attached great importance to these hands-on experiments in science learning, but it was not mandatory for teachers to replace hands-on experiments with science videos. In areas without sufficient laboratory and experimental equipment support, science videos, as an equivalent teaching method to hands-on experiments, could also encourage teachers to try using science videos for teaching rather than giving up on guiding students in scientific exploration. We encourage students to conduct scientific and rigorous hands-on experiments if schools have sufficient conditions, and teachers should give students different levels of learning goals. If teachers emphasized more experience and perception, traditional hands-on experiments could be provided. If the focus is on constructing, understanding, and providing evidence, alternative solutions that are more economical in terms of time and price could also be found.

Impact on health awareness

In our study, there were also two manifestations of health awareness in the hands-on experiment class: the hands-on experiment class had significantly higher health awareness of protecting the body when learning through more precise simulation experiments than the class watching videos, and the difference between the two teaching methods was not significant when learning through imprecise simulation experiments. This might mean that for elementary school students who are transitioning from visual thinking to abstract thinking, first-hand experience is indeed more conducive to their emotional identification with healthy habits. However, less precise experiments are harder to perform. In this study, there was no significant difference between the two classes in the health awareness assessment of the "Heart and Blood" lesson. This indicates that watching videos is just as effective as performing imprecise simulations. Therefore, we suggest that the precision of the experiment should also be an important basis for teachers to consider whether to replace hands-on experiments with science videos.

The following shortcomings have limited this study. First, the experimental effect of the two lessons was not sufficient to reveal the general teaching effect, and more exploration should be conducted in the future. Second, the effect of using science video teaching was not compared with the effect of textbook-based science teaching. In the future, traditional teaching classes should be added for comparative experimental research. Third, the assessment relied too much on paper-and-pencil tests, and interviews with teachers and students should be added in the future to understand how they expect and build their understanding of scientific knowledge when teaching and learning simulation experiments. So we can better understand the deeper reasons why hands-on experiments don't work as well as they should.

Conclusion and suggestions

Our current research draws the following conclusions: (1) based on the results of scientific knowledge and modeling ability, schools that lack the conditions to conduct experimental teaching could use science videos instead of hands-on experiments to carry out science teaching; (2) for elementary school students, hands-on experiments still have certain advantages in cultivating an awareness of healthy living; and (3) for primary school science teaching, the preciseness of experiments affects the effectiveness of teaching and is a factor that affects whether videos can be used as a substitute.

To this end, we propose the following teaching suggestions: First, when using science videos for teaching, finely edited videos with high task relevance should be used for the learning content (Lowe, 2004). Second, technology personnel and teachers should jointly develop science video resources. Rich video content could lead to information overload and selective exposure (Takahashi & Tandoc, 2015) when the quantity of videos is too large or there is a lack of information gatekeepers in terms of quality (Shapiro & Park, 2014). It is necessary for all stakeholders to collaborate and actively contribute their wisdom. Third, learners need scaffolding to generate constructive discourse (Nussbaum et al., 2009). When using science videos for teaching, teachers should use videos as materials to support students' thinking rather than directly using videos as a substitute for teacher guidance. Fourth, for students in the stage of visual thinking, tactile perception of real objects is necessary. Schools with laboratory conditions should still support students in conducting hands-on experiments. When laboratory conditions are not available, students should first be allowed to perceive real objects, such as the position of their limbs and hearts, before they are explained through science videos.

Appendix

Number	Gender	Age	Teaching age	Major	Body movement			Heart and blood		
					Knowledge	Modeling	Health	Knowledge	Modeling	Health
T1	Female	33	11	Life science	√	√		√		√
T2	Female	32	10	Science education	√			√	√	√
T3	Male	31	9	Science education	√			√	√	√
T4	Male	49	30	Pedagogy	√			√	√	√
T5	Female	37	13	Chemical education	√	√		√	√	√
T6	Female	35	13	Biological science	√		√	√	√	√
T7	Female	34	12	Science education	√			√		√
T8	Male	37	15	Geography education	√			√		
T9	Male	31	5	Physics education	√			√		√
T10	Male	43	21	Biological education	√			√		
T11	Female	32	7	Optics	√	√		√	√	
T12	Male	29	7	Physics education	√	√	√	√	√	√
T13	Female	30	5	Ecology	√	√	√	√	√	√
T14	Female	42	17	Chemical education	√	√		√	√	√
T15	Female	39	17	Primary education	√	√		√		√
T16	Male	55	33	Mathematics education	√	√		√	√	
T17	Female	27	3	Science education	√			√	√	
Total					17	8	3	17	11	12

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Author contributions
SF designed the study and was a major contributor in writing the manuscript. TL conducted a quasi-experimental study and scored the test. ZH analyzed the data and guided the writing.

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Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests
The authors declare that they have no competing interests.

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