MODESTUM EURASIA Journal of Mathematics, Science and Technology Education, 2024, 20(7), em2466
ISSN:1305-8223 (online)
OPEN ACCESS Research Paper https://doi.org/10.29333/ejmste/14706

Using hands-on learning video assignments in online and in-person contexts: A longitudinal study

Qingqing Ji [1], Ronghua Zhang [2*], Xiaoyun Duan [2], Jennifer N. Tripp [3], Xiufeng Liu [3], Chenyang Cheng [2]

[1] College of Teacher Education, Northwest Normal University, Anning District, Lanzhou City, Gansu Province, CHINA
[2] Faculty of Teacher Education, Shanxi Normal University, Xiaodian District, Taiyuan, Shanxi, CHINA
[3] Department of Learning and Instruction, University at Buffalo, Buffalo, NY, USA

Received 15 January 2024 ▪ Accepted 23 May 2024

Abstract
This study investigated the use of hands-on learning video assignments (HLVAs) among middle school students in China during and after the COVID-19 pandemic. Based on the results of HLVAs approach with seventh grade students at Jiefang Road School during the online learning phase, one class was selected to participate in an offline empirical, longitudinal study to further explore the impact of HLVAs approach on students' biology learning. Two data collection instruments were used: hands-on learning students' work evaluation instrument and model competence development instrument to detect changes in students' modeling development. Questionnaire responses from the students in the experimental class two years later, when they were in high school, offer additional perspectives on this approach. Findings indicated that HLVAs approach improves students' work quality, modeling skills, and biology learning outcomes. This study describes hands-on learning strategy based on embodied cognition theoretical perspectives, with implications for curriculum, instruction, and learning.

Keywords: hands-on learning, video assignments, modeling skills, science instruction

INTRODUCTION

On May 5, 2023, World Health Organization (WHO, 2023) determined that COVID-19 no longer constituted a public health emergency of international concern and announced the official end of the COVID-19 pandemic. Presently, all schools in China have returned to their previous teaching state, with students attending classes and studying as usual without the need for home isolation, and remote teaching is rarely conducted. Despite this announcement and return to in-person instruction, educational practices during the pandemic provide an excellent analytical lens for us to reimagine education. Seemingly overnight several years ago, most classrooms within schools, colleges, and universities the world over were forced to convert to emergency remote teaching and learning formats (Hodges et al., 2020) and online teaching and learning (Crawford et al., 2020). The transition from a traditional classroom to a virtual classroom, complemented by advanced communication technologies, has brought challenges not only associated with teachers' online tools, platforms, and enabling technologies but also with effective teaching and learning for PK-12 science education.

Online learning, also known as e-learning, has been defined as students working online while the teacher assigns work and checks in digitally (Asim & Hollenbeck, 2021; Hollenbeck, 2021; National Science Teaching Association [NSTA], 2016; Sekulich, 2020; Stauffer, 2020; Trust & Whalen, 2020). During the pandemic, teachers in China engaged in online, remote instruction. Science teachers can effectively implement online learning through well-planned activities and attending to active learning strategies, student motivation, and formative feedback (Wisanti et al., 2021; Yengin et al., 2010). In the post-pandemic era, online learning has become an auxiliary teaching approach for teachers in China. Nevertheless, in-person teaching has

✉ 328934893@qq.com ✉ zhangzilf@126.com **(*Correspondence)** ✉ 2578243011@qq.com ✉ jntripp@buffalo.edu
✉ xliu5@buffalo.edu ✉ 15735513836@163.com

Contribution to the literature

- Describes implementation of Hands-on Learning Video Assignments (HLVAs) teaching approach in fully online, hybrid, and fully in-person contexts in a middle school biology course.
- Develops students' hands-on learning works evaluation instrument to evaluate the quality of students' video work and adapts model competence development instrument to evaluate students' modeling skills.
- Quantitatively explores the effectiveness of HLVAs instruction strategy and offers recommendations for future science teaching, undergirded by embodied cognition theoretical perspectives.

largely replaced online teaching due to middle school teachers' pedagogical preferences and beliefs about the benefits of in-person instruction for students' well-being. Additionally, researchers have highlighted the value of authentic science experiential activities that support students' hands-on learning and development of understanding (Ates & Eryilmaz, 2011), while also having potential to make science fun for both students and teachers (Haury & Rillero, 1994). Given more recent attention to anxiety and stress exacerbated by the COVID-19 pandemic, along with increased recognition of emotions, such as joy, and their critical role in disciplinary learning (Jaber & Hammer, 2016), enjoyment in science learning seems a worthy goal and point of consideration when making decisions about science instructional approaches.

Studies have explored various hands-on learning approaches typically conducted in biology classrooms, such as experimenting, dissecting, working with microscopes, classifying creatures (Holstermann et al., 2009), making observations, and designing models and games (Yildiz, 2014). However, due to the quarantine isolation of teachers and students during the COVID-19 pandemic, hands-on, embodied experiments and observations were more difficult to carry out. Nevertheless, students could make models and record their learning processes using portable electronic devices, such as smartphones and tablets. Studies have documented the benefits of strategically integrating these portable electronic devices in education, such as positive learning outcomes (Wilkinson & Barter, 2016), positive attitudes towards learning (Gorhan et al., 2014), active engagement in the learning process (Mang & Wardley, 2013), and improved critical thinking and creativity (Wilkinson & Barter, 2016). Conversely, others have pointed out that the use of portable electronic devices in teaching and learning is still a relatively underdeveloped approach that needs further examination (Haβler et al., 2015). Crompton and Burke (2020) found that 46.0% of the time, mobile devices were used to replicate activities that could be conducted without technology involving mobile devices in PK-12 (two-18 years old) learning.

It is important to note that it is not the device itself that will automatically promote these benefits but rather the ways in which the devices are used in line with effective teaching and learning principles to further extend learning in new ways. Considering parents' concerns about their children's frequent use of portable electronic devices, and in order to combine hands-on learning with effective online teaching and learning, we have developed a new teaching strategy to improve learning. Hands-on learning video assignments (HLVAs) are model-making tasks designed and assigned by teachers for students according to their teaching needs. Students record hands-on learning videos offline and upload them to corresponding platforms. Teachers check students' completion through online platforms to keep track of students' learning situations and further arrange teaching plans. Through hands-on modeling, students can better grapple with ideas, cultivate their hands-on skills, and develop scientific thinking.

Before the pandemic, there were two primary ways to implement models as learning tools in China. With the first approach, teachers created models to demonstrate for students without allowing them to participate in hands-on modeling activities. With the second approach, students created models for the presentation of results, and only students with exemplary work as designated by teachers acted as representatives in the classroom to operate the models and explain the scientific significance of them. Each of these approaches did not fully mobilize all students' embodied cognition capabilities, which affects their learning. Moreover, modern information technology, such as smartphones, were not fully utilized to support students' scientific learning. During the pandemic, in the midst of online teaching, students were encouraged to use smartphones to report their health conditions, which inspired us to encourage students to use smartphones to report their homework progress as well as their scientific learning process of developing, using, and explaining models.

In order to verify the feasibility and effectiveness of HLVAs approach, we conducted an empirical, longitudinal study including a quasi-experimental design and questionnaires. This study starts with all seventh-grade students and then focuses on one class for intensive study, examining the longitudinal effect of HLVAs teaching strategy, with insights on what education systems can do to provide quality science instruction and appropriate teacher support during times of crisis and beyond. At the beginning of the 2020-2021 academic year, students were required to

(1) produce models of human organs and body systems using inexpensive materials,
(2) manipulate models and provide scientific explanations,
(3) video record their scientific explanations of the modeling process using portable electronic devices,
(4) upload HLVAs to their teachers for evaluation, and
(5) accept feedback and improve their biology learning.

The purpose of this series of operations is to enable students to learn how to use information technology to carry out scientific learning activities such as learning by doing, operating models, explaining scientific concepts, and promoting the development of embodied cognition and scientific literacy.

LITERATURE REVIEW

Hands-On Learning & Embodied Cognition Theoretical Perspectives

Hands-on learning, also referred to as practical learning or learning by doing, has long served as a well-regarded, important learning tool and teaching approach in science education since the 1960s throughout the world (Bigler & Hanegan, 2010; Flick, 1993; Haury & Rillero, 1994; Jazwa, 2017; Lumpe & Oliver, 1991; Schneider, 2016; Triona & Klahr, 2007). Active learning, situated learning, constructionist learning, and project-based learning, among other approaches, often involve some form of hands-on learning. In recent years, hands-on learning has become a popular buzzword in humanities curricula (Jazwa, 2017). Jazwa (2017) argued that the nature of hands-on learning is also applicable in science course learning, where students can engage directly and physically with objects to gain experiential knowledge about a certain topic or techniques.

Embodied cognition suggests that the physical body plays a significant causal role, or a physically constitutive role, in cognitive processing (Foglia & Wilson, 2013). Embodied cognition scholars argue that the body is indeed essential in the production of cognition (Varela et al., 1991) and that cognitive processes are based on–or are at least moderated by–sensorimotor processes (Barsalou, 2016; Mahon & Caramazza, 2008; Zona et al., 2018). Put differently, our physical interaction with the world influences our cognition (Kemmerer et al., 2013; Shapiro, 2014). An embodied perspective on cognition holds that "cognitive processes are rooted in the actions of the human body in the physical world" (Alibali & Nathan, 2018, p. 75). Embodied cognition has extended its reach into "4E cognition" in which cognition is not only embodied, but embedded, extended, and enacted (Gallagher, 2005; Rowlands, 2013). In particular, embedding essential problem-solving and discovery components requires students to think multidimensionally and innovatively about topics that align with natural human learning processes.

Hands-on science activities can be integrated into science classrooms and laboratories, as well as a wide range of settings, and incorporate the science practices of observation, measurement, and modeling. In hands-on learning activities, hands are moved, but the entire body-mind is stimulated by physical activity. According to embodied cognition theory, physical activity can create higher cognitive development through operation internalization; thus, physical activity is more than the source of perception; it is also the basis of thinking development (Lakoff & Johnson, 1999). As such, the human body plays a central role in cognition, and physical activity itself promotes cognitive development (Dewey, 1938; Lakoff & Johnson, 1999). With this perspective, in hands-on learning, the body of the learner is recognized as embedded in its dynamic environment, where the mind, body, and world cannot be separated because they mutually interact and play important roles in learning.

Holstermann et al. (2009) pointed out that the hands-on learning strategy has increased learners' understanding of scientific concepts through manipulating objects, which makes abstract knowledge more concrete. Likewise, Hirca (2013) and Pirttimaa et al. (2015) indicated that hands-on learning can help students acquire and apply their knowledge, such as through developing feasible solutions to problems. Numerous researchers have also explored the relationship between hands-on science and student learning (Ates & Eryilmaz, 2011; Louca & Zacharia, 2012; Ruby, 2001) and attitudes towards physics (Ates & Eryilmaz, 2011), biology (Yildiz, 2014), and chemistry (Kibga et al., 2021). Specifically, Prokop and Fančovičová (2016) found that hands-on activities in biology and science education improved children's attitudes toward science. In a study of hands-on learning conducted by Klahr et al. (2007), children were able to learn as well with virtual materials as compared with physical materials. Students' interests in experimenting, working with microscopes, and dissecting and classifying were positively correlated with the quality of their engagement in hands-on learning experiences (Holstermann et al., 2009).

In recent years, hands-on learning has also been linked with modern information and communications technology. For example, Liu (2006) demonstrated that computer-based activities and hands-on activities were more effective when used in combination rather than separately in terms of understanding gas laws. Chen (2019) combined virtual reality technology, 6E (engage, explore, explain, engineer, enrich, and evaluate) model, and STEM (science, technology, engineering, and mathematics) education to investigate how hands-on activity influenced students' behavioral learning patterns, and the results showed that all students' learning performances and hands-on abilities were enhanced. Although previous research on hands-on learning in science has offered beneficial outcomes, the connections to modeling and students' modeling skills has not often been explored or emphasized.

Models & Modeling Skills

Models are considered effective pedagogical tools for furthering scientific literacy (Halloun, 2006). Models refer to the representations of objects, phenomena, processes, ideas, and/or their systems (Gilbert et al., 2000; Werner et al., 2017). Models, especially physical models, can serve as an effective tool for learning biology (Krell et al., 2013) and have been used to explain and understand phenomena in nature (Henze & van Driel, 2011; Justi & Gilbert, 2002). In fact, developing and using models are one of the core science and engineering practices woven throughout the next generation science standards (NGSS), where models can serve as visual and conceptual representations of students' understandings of science, and students are encouraged to produce, critique, and revise them (Bryce et al., 2016; NGSS Lead States, 2013).

Physical models can be further divided into two-dimensional and three-dimensional physical models (Upmeier zu Belzen, 2013). This definition attributes structural and functional models as three-dimensional physical models and diagrams and symbols as two-dimensional physical models and mental models (Steinbuch 1977; Upmeier zu Belzen, 2013). Additionally, three-dimensional (3D) printing represents an emerging, cost-effective means of producing molecular models to help students investigate structure-function concepts (Lombard et al., 2023). Often, learning is seen solely as a mental activity, even though it is also an activity that recruits the mind and body. In embodied cognition theory, the body, sensory, and motor processes are one inseparable entity in cognition (Sullivan, 2018). From this perspective, students' construction of hands-on models is a process of sensemaking and understanding models.

Science Education & Online Learning

Science is not just a body of knowledge that reflects current understanding of the world; it is also a set of practices used to establish, extend, and refine that knowledge. Although researchers have stated that science was the most difficult subject to teach virtually (Kurtz, 2020), they have also noted that, given the right support and strategies, teachers can be successful at engaging students in meaningful online science learning experiences (Rapanta et al., 2020), such as the broadcasting of educational programs through traditional media such as radio or television in Latin America and the Caribbean (Breslyn & Green, 2022; Uribe, 2020). However, difficulties and challenges of teaching and learning biology through virtual approaches remain (Wisanti et al., 2021). In science education, where the content is often presented in an abstract nature, the design of embodied representations that connect to the studied natural phenomena in an analogical fashion–such as a model–becomes central (Gregorcic & Haglund, 2018). As with in-person instruction, when online learning consists of teachers talking and students listening in ways that minimize students' active involvement in hands-on, minds-on learning, abstract scientific concepts remain loosely accessible at the surface, eluding deep understanding.

The COVID-19 pandemic has heightened attention towards the educational value of hands-on, minds-on learning integration using electronic devices. Much greater use of embodied cognition theoretical perspectives can be used in instructional design by purposely connecting mental and bodily processes to interactions with the environment (Castro-Alonso et al., 2014). This study examines the impact of HLVAs approach, where students

(1) engaged in cutting, drawing, creating, and manipulating models of human organs and organ systems using low-cost materials found around the home,

(2) explained the scientific knowledge or principles of their models,

(3) videorecorded their learning process, with a particular focus on identifying structures and explaining their functions using a portable electronic device such as a mobile phone, and

(4) uploaded the video to their teachers for evaluation and feedback.

We examine the impact of this hands-on learning approach on students' modeling abilities and biology learning in both online and offline biology teaching. Specifically, this study examines the following research questions:

1. What are the characteristics of students' hands-on learning work in a variety of contexts?
2. What is the effect of HLVAs approach on students' modeling skills and biology learning?
3. How much impact does HLVAs approach have on students' learning after two years?

METHODOLOGY

Research Setting & Participants

This study was conducted with seventh graders at Jiefang Road School, in Linfen City, Shanxi Province, China and included two phases: HLVAs instruction strategy training phase (March 2020 to June 2020, online) and experimental study phase (September 2020 to February 2021, offline). Jiefang Road School is a nine-year compulsory school located in the urban-rural fringe, with 395 students in eight classes from surrounding communities.

Participants in the online phase included 234 students in four classes (classes 57, 58, 59, and 60). Not really satisfied with the results of the study at this stage, after reflection, the researchers decided to narrow the study's scope and conduct further investigations. Class 57 (with 20 male and 28 female students, including one student classified with an intellectual disability and another with a motor disability) was randomly selected as the experimental class. There was no control class in this study because all students in this grade had used HLVAs learning approach in the online stage, all of them were affected to a certain degree, and the effectiveness of the control of variables could not be guaranteed. In summary, we conducted a single-group pretest and posttest quasi-experimental design.

Course Description & Research Design

In China, the middle school biology curriculum includes four units: botany, zoology, human physiology, and ecology, which is designed to be completed in two years across four semesters in the seventh and eighth grades. Biology is not an exam subject for the high school entrance examination, although biology experimental skills test scores are part of the high school entrance examination in some regions. Therefore, compared with other exam subjects, middle school biology teachers feel a greater sense of agency to teach science in reform-based ways, using innovative experiments and creative teaching approaches.

During the online training phase (March 2020 to June 2020), all students in the four, seventh grade classes took part in hands-on learning instruction. Students were asked to complete hands-on learning work after school. First, they constructed a model using inexpensive materials. Next, they reflected on what the model represented and their associated science knowledge. Finally, they made a video with their parents' help, shared their explanations, and uploaded the explanatory videos to the Ding Talk, which is an enterprise level collaborative office and application development platform. Ding Talk was one of the most widely used online education platforms during the epidemic in China.

The content of the curriculum included the discharge of waste from the human body and the human body's perception of the external environment, involving three themes for student work assignments: the structure of the nephron, the structure of the eyeball, and the structure of the ear. Students' assignments were collected within one or two weeks after learning tasks were assigned once per month. There were 151 videos submitted out of 331 assignments, accounting for 46.0% of the total number of assignments. This result suggested that perhaps students were not highly motivated to participate in the new teaching strategy during the online stage or that they had difficulty completing the assignment tasks. The relatively low submission of assignments limited our understanding of the real impact of HLVAs approach on students' learning. Additionally, whether the cause of this phenomenon was due to a problem with HLVAs approach itself, the nature of the online teaching modules, or other complex challenges students faced during the pandemic, was unknown. Therefore, researchers decided to conduct further small-scale research during the offline stage.

During the offline experimental study phase (September 2020 to February 2021) when students learned science fully in-person and occasionally hybrid, students in the experimental class in eighth grade completed hands-on learning work and uploaded their videos to the Ding Talk. There were three dependent variables, such as students' work quality, modeling skills, and biology learning achievement.

The off-line learning phase had five tasks. Most students submitted their assignments at that time. Only five students' assignments about coelenterates were not submitted, and twelve students' assignments for mollusks were not collected in the same way. To increase assignment submission and engage students, the following modifications were made:

(1) increase proper teacher supervision,

(2) change the submission methods for hands-on learning work, and

(3) create opportunities for peer learning.

In particular, two of the authors of this paper intervened for the first time, one being the first author and the other being the third, coordinating with the class teacher to have students complete their work assignments of fish as part of the third learning task during extracurricular activity time and to record and upload the video to the Ding Talk at home. There were 35 assignments lacking explanatory videos, requiring a second intervention to allow students to record and upload homework using school resources, whether they completed their models at school or home. After the second intervention, 36 bacteria and 36 virus hands-on learning work assignments were submitted, and 75.0% of the students returned their assignments. Good and excellent work samples were displayed in classrooms to further student recognition and pride and to encourage peer review and learning. In this way, students could examine and reflect on these models of exemplary work before each learning task. The number of student assignments and types collected in the two phases are shown in **Table 1**.

Table 1. Hands-on learning video assignment instruction research process & work assignments

			Training phase (online)	Experimental study phase (off-line)
Purpose			Applying & adjusting teaching methods, familiarizing students to new teaching methods, & developing evaluation tools.	Implementing interventions & evaluating teaching effectiveness.
Participants			234	48
Assignment theme & number of assignments*			Nephron: 173, eyeball: 102, & ear: 56	Coelenterates: 43, mollusks: 36, fish: 35, bacteria: 36, & viruses: 36
Assignment work location			Home	School & home
Number & kinds of student work	Model	3D physical model	80	135
		2D physical model	248	51
		Electronic model	3	0
		Total	331	186
	Video		151	130

Note. *Number after colon refers to number of assignments collected for that theme

Data Collection

This study is an empirical, longitudinal study that includes a quasi-experimental design and questionnaires (Shavelson & Towne 2002). Quantitative data was collected from the experimental class. This data includes scores of students' hands-on learning work quality that were evaluated through scoring five assignments using *students' hands-on learning work evaluation instrument*. Another form of quantitative data included the modeling ability scores from *model competence development instrument*, and the third involved biology achievement test scores. The pre- and post-test results of the experimental class were derived from the biology results of the final exam in the online and offline stages. The final exam is organized by the education bureau of Yaodu District, Linfen City, Shanxi Province. As a district-wide exam, testing experts were chosen from the entire school district and had extensive experience in measurement and evaluation, and biology teaching and learning, which ensured expert validity of the examination. Cronbach's alpha, which is the most commonly used reliability assessment tool in educational tests, is 0.75, which meets the reliability requirements (Taber, 2017).

Students' hands-on learning work evaluation instrument

Students' hands-on learning work evaluation instrument, hereafter referred to as instrument A, was developed to evaluate students' work assignments by using the analytic hierarchy process (AHP) and an AHP software, yet another analytic hierarchy process (YAAHP) software, where Spearman rank correlation coefficient for the consistency reliability coefficient between raters was 0.952 ($p=0.010<0.050$) (Duan, 2021; Zhang et al., 2021). Instrument A had three first-level indicators: *promoting learning as a learning tool*, *basic characteristics of the work*, and *embodied thinking*, with several second-level indicators for each first-level indicator. Different levels were assigned different weights for different indicators.

Table 2 shows the scoring rubric for student work. For each category of student work, a group of subcategories, which is referred to as student work indicators, is defined. The quality of student work, according to the three, first-level and thirteen, second-level indicators, were assessed by the first and third authors and a score (*none*-0, *unqualified*-1, *qualified*-2, *good*-3, and *excellent*-4) was assigned to each indicator. The overall score of each student's work was computed by adding the scores of all indicators times its weight (see **Table 2** example); then, averages of the total scores of students' work quality were used in further analyses. For example, a male student submitted four work assignments except for the virus assignment, with scores of 2.83 (coelenterate), 2.22 (mollusk), 3.00 (fish), 2.59 (bacteria), and 0 (virus), evaluated using Instrument A, with an average score of 2.128. Finally, 151 explanation video assignments from 194 students were scored during the online phase, including 48 experimental students, while 130 videos from 48 students were scored during the offline phase.

Model competence development instrument

Model competence development instrument, hereafter referred to as instrument B, was used to evaluate students' modeling skills. Instrument B was adapted from the model of model competence (Krell et al., 2013), which distinguishes the five aspects: *nature of models*, *multiple models*, *purpose of models*, *testing models*, and *changing models*, and three (aspect-dependent) levels of understanding have been proposed for each aspect (Upmeier zu Belzen & Krüger, 2010). However, there is a lack of measurement for utilizing models to learn. Thus, view of the model as a learning tool as one dimension was introduced, and three levels have been distinguished: Level 1, *no impact, only delaying learning*; level 2, *promoting the knowledge of the model objects*; level 3, *both promoting knowledge and practical skills*. As a result, the final questionnaire consisted of 6 dimensions and 18 questions, and 48 students from the eighth-grade

Table 2. Evaluation indicator system of hands-on learning video assignments

First-level indicators/weight	Second-level indicators/weight	Index description	Rating E	Rating G	Rating Q	Rating UQ	S
Promoting hands-on learning as a learning tool/0.62	Visualizing knowledge/0.22	The knowledge involved in the prototype is visibly presented more fully in the products.	4				0.88
	Conceptualizing knowledge/0.11	Scientific concepts and their interconnections are presented clearly and systematically in the video.		3			0.33
	Emphasizing key knowledge/0.19	Visual demonstration of key concepts and tips for understanding concepts are clearly demonstrated.		3			0.57
	Explaining knowledge/0.10	The biological knowledge contained in the model is accurately demonstrated and explained in the video.		3			0.3
Basic characteristics of work/0.25	Scientific/0.08	Student work accurately and realistically displays the characteristics of the phenomena to be modeled, including the size, morphological characteristics, proportion, relative positioning, etc.		3			0.24
	Similarity/0.03	Student work simulates form or appearance and the physiological functions and processes.		3			0.09
	Simplicity/0.06	Student work is simple, clear, and the composition of the structure is easy to distinguish.		3			0.18
	Worthwhile/0.05	Student work has potential to engage others' interest in observation, operation, and even imitation of product.		3			0.15
	Aesthetics/0.03	Student work is designed well and exquisitely manufactured with details.		3			0.09
Value of embodied thinking/0.13	Manipulability/0.05	Student work could be used to conduct their work & show physiological function & processes correctly.		3			0.15
	Innovative/0.03	Design ideas and materials selected are unique.		3			0.09
	Multi-disciplinary thinking/0.03	Student work relates with physics, information technology, & other multi-disciplinary knowledge systems.		3			0.09
	Practicality/0.02	Student work is worthy of being popularized with the low-priced materials and easy to obtain and use.		3			0.06
Total							3.22

Note. E: Excellent; G: Good; Q: Qualified; UQ: Unqualified; & S: Score

experimental class at [name masked for review] School were selected for a pretest and posttest.

Experimental class student investigations

Three investigations were used to understand the influence of HLVAs approach on experimental students' learning through questionnaires. The first and second questionnaires were conducted after the end of the experiment, and the last questionnaire was conducted two years later.

Investigations immediately after experiment: Immediately after the end of the experiment, two questionnaires were conducted. The first investigation by paper questionnaire was conducted during the experimental phase at the end of the experiment by the first and third authors, which involved all students in the experimental class and mainly aimed to investigate students' understanding of HLVAs.

The first investigation questions were:

(1) To what extent are you interested in hands-on learning?

(2) How often do you use hands-on learning in your daily life?

(3) What is the likelihood of gaining a sense of accomplishment in hands-on learning?

(4) To what extent do you feel hands-on learning stimulates creativity?

(5) To what extent do you feel that the school curriculum limits hands-on learning?

(6) To what extent do you feel that you often resist hands-on learning?

The answers to the six questions were scored on a four-point scale, with scores ranging from one to four indicating varying degrees of agreement or other attitude orientations.

Also, a second investigation was conducted directly after the experiment for ten students in the experimental class to understand students' perceptions of hands-on learning and complement the lack of quantitative analysis of students' modeling abilities.

The researchers prepared paper questionnaires in advance, and the students filled in the questionnaires. Five students, who had been randomly selected from students who submitted four or more assignments, were surveyed by questionnaire A (Q-A), and the other five students, randomly selected from students who submitted three or fewer assignments, were surveyed by questionnaire B (Q-B). In Q-A and Q-B, there were two questions designed to be the same (question 1 and question 2):

(1) What was your attitude towards the learning tasks assigned by the teacher? Could you please talk about the reasons that led you to like or dislike the tasks?

(2) Have you ever seen the work assignments of other classmates? Please choose one example and share what inspiration it had for you.

The rest of the questions were different between the two types of students. For the five students surveyed by Q-A, students were asked three questions about whether they communicated with peers before or during the completion of the hands-on learning tasks; what was helpful for their biology learning; and how long it took students to complete the hands-on learning tasks. For the other five students who were surveyed by Q-B, students were asked two questions, for example, the reasons why they were unable to complete their assignments on time and what the impact of uncompleted submissions had on their biology learning.

Investigation two years after experiment: The third investigation was conducted by the first and second authors two years after the end of the experiment when students had already entered high school. In China, people generally use a social media app called WeChat, which is developed by Tencent and is similar to Facebook. For this study, a class group was formed using WeChat software, which has been in use since students' enrollment and has not yet been disbanded.

During the three years of junior high school, this WeChat group was used to assign homework, post learning tasks, and manage classes for students, helping to better connect teachers and students. After graduation, this group became a platform for emotional and social communication among students. Through this platform, students shared their learning progress in their respective high schools and regularly organized invitation gatherings. This platform also offered a venue to publish follow-up questionnaires.

To explore the lasting influence of HLVAs approach, students were asked five questions via an electronically distributed questionnaire:

(1) What is your impression of HLVAs approach?

(2) In what ways, if any, was this teaching method helpful for your high school learning?

(3) To what extent do you miss this learning experience?

(4) Have you made a biological model and video explanation before this learning experience? and

(5) Do the teachers in your current school use HLVAs approach?

The answers to question 1 and question 3 were scored, ranging from one to five, indicating varying degrees of impact. The higher the score obtained, the higher the level of impact, and the other two questions were close-ended with a yes/no response. For this investigation, 32 students (14 males and 18 females) were contacted over the Internet. Except for two students who were admitted to vocational high schools, all other students went to traditional high schools. Specifically, 27 students went to public high schools, while three went to private high schools.

Data Analysis

Evaluation indicator system of HLVAs is shown in **Table 2** and was used to score students' hands-on learning video assignments. After all assignments were rated, the average score of each student was calculated. Then, the quality of students' work was divided into four levels: an average score of three-four points (including three points) as excellent, two-three points (including two points) as good, one-two points (including one point) as qualified, and below one as unqualified. Student work was rated according to four levels such as *excellent*, *good*, *qualified*, and *unqualified*, and the number of students at four levels was calculated. t-tests were used to detect the difference in students' learning quality before and after the experiment, and correlation analysis was used to determine the relationship between the quality of students' hands-on learning work assignments and their modeling skills. Questionnaires were analyzed through frequency of responses and thematic analysis.

Reliability & Validity

Credibility and validity of this study was supported by the triangulation of multiple forms of evidence, including analysis of students' work samples and questionnaire responses to demonstrate the effectiveness of HLVAs approach. Additionally, this study's reliability and validity were attended to along three aspects:

(1) the development of instrument A and instrument B,

(2) rating students' work and modeling skills, and

(3) data analysis.

The development of instrument A involved the opinions of middle and high school biology teachers and university biology education researchers (Duan, 2021; Yang et al., 2020; Zhang et al., 2021) and have been published in *Journal of Biology Teaching*, edited and published by East China Normal University. Two raters evaluated students' work. One was a science education lecturer who has more than 16 years of middle school biology teaching experience, and the other one was a biology master's degree student with one year of biology teaching experience. The two raters were also

Figure 1. Number of different quality levels of students' hands-on learning video assignments in online phase (n=194) (Source: Authors' own elaboration)

researchers and had extensive expertise and knowledge on hands-on learning and biology education. Considering the difficulties of this evaluation, which is different from ordinary rating, the researchers conducted the scoring in three steps. They first evaluated the effectiveness of the model as a learning tool by watching videos and listening to students' scientific explanations. Next, they evaluated the characteristics of the objects operated by students in the videos based on four aspects: scientific, similarity, simplicity, worthwhile, and aesthetics. Third, they judged the value of embodied thinking in the learning process.

Facing assessment tasks that were different from usual, they deeply discussed the scoring procedure. Then, 10 student work samples were selected and independently rated by the two raters; the resulting inter-rater reliability was calculated with Spearman's rank correlation coefficient, which showed an acceptable level (Duan, 2021; Zhang et al., 2021). They then continued the process to complete the scoring for the rest of the student work samples, except for the 10 work samples used for reliability testing.

As for instrument B, the students were scored one for level 1; they were scored with two for level 2; and with three for level 3 (Krell et al., 2013). The internal consistency reliability coefficient for each dimension and total scale of instrument B were demonstrated with the coefficient alpha ranging from 0.6 to 0.7, belonging to a high reliability range. Specifically, the total was 0.741, and from dimension 1 to dimension 6: 0.762, 0.718, 0.766, 0.680, 0.675, and 0.714, respectively.

RESULTS

Descriptive Statistics & Examples of Students' Hands-On Learning Video Assignments

Figure 1 shows the number of students from four classes (classes 57, 58, 59, and 60) who attained each quality level for the assignments during the online learning phase, demonstrating that the quality of students' work needed improvement.

Figure 2. Number of experimental class students at each quality level for hands-on learning work during online & offline phases (n=48) (Source: Authors' own elaboration)

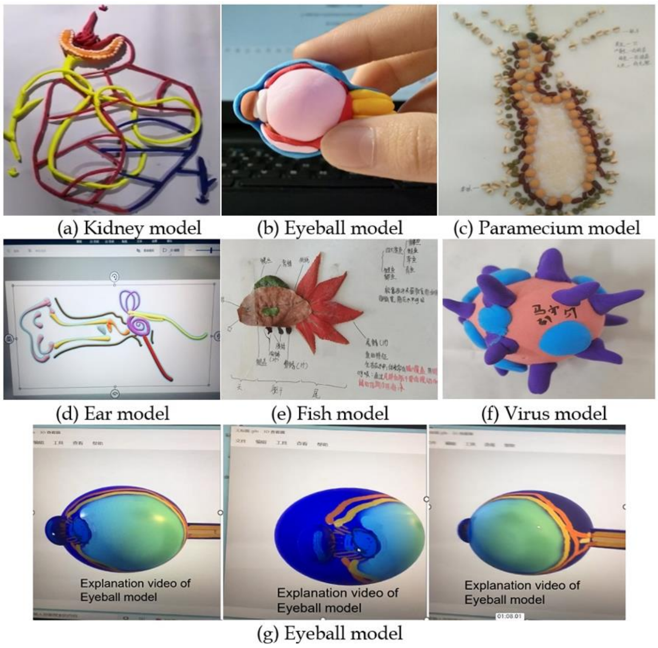

Figure 3. Examples of experimental class students' models (Source: Authors' own elaboration)

Figure 2 shows the difference before and after the experiment of the experimental class students' hands-on learning work quality, demonstrating that the number of excellent and good student work samples increased, while the number of qualified and unqualified decreased. The results show that the quality of the experimental students' work has improved.

Figure 3 displays examples of students' models, which reflects their strong creativity. The models they created not only used specialized clay materials (parts a, b, and f), but they also used more environmentally sustainable and imaginative biomaterials around them, such as leaves (part e) and beans (part c). Most notably, students integrated information technology in hands-on learning. For example, two male students submitted an electronic model of the ear (part d) and eyeballs (part g), produced using 3D software, and the eyeball model could rotate when student introduced the various structures of the digital eyeball in the video (part g).

Table 3. Descriptive statistics for experimental students' work quality test & paired samples t-test for equality of means (n=48)

	M	SD	SEM	95% CI of difference		t	df	Sig. (2-tailed)
				Lower	Upper			
Online phase-off-line phase	-.232	.708	.101	-.536	-.129	-3.287	47	.002

Note. M: Mean; SD: Standard deviation; SEM: Standard error of mean; & CI: Confidence interval

Table 4. Descriptive statistics for experimental class students' modeling abilities test & paired samples t-test for equality of means (n=48)

		M	SD	SEM	95% CI difference		t	df	Sig. (2-tailed)
					Lower	Upper			
Nature of models	Aspect1 pre-test-aspect1 post-test	-.021	.956	.138	-.299	.257	-.151	47	.881
Multiple models	Aspect2 pre-test-aspect2 post-test	.000	.968	.140	-.281	.000	.136	47	1.000
Purpose of models	Aspect3 pre-test-aspect3 post-test	-.042	.967	.140	-.322	.239	-.299	47	.767
Testing models	Aspect4 pre-test-aspect4 post-test	.083	1.302	.188	-.295	.461	.443	47	.659
Changing models	Aspect5 pre-test-aspect5 post-test	-.083	1.108	.160	-.405	.238	-.521	47	.605
Impact of model as an LT	Aspect6 pre-test-aspect6 post-test	-.479	1.255	.181	-.843	-.115	-2.646	47	.011

Note. M: Mean; SD: Standard deviation; SEM: Standard error of mean; CI: Confidence interval; & LT: Learning tool

Table 5. Descriptive statistics & paired sample t-test for pre- & post-test of biological performance in experimental class (n=48)

	M	SD	SEM	95% CI of difference		t	df	Sig. (2-tailed)
				Lower	Upper			
Pre-/post-test	-3.146	8.769	1.266	-5.692	-.600	-2.485	47	.017

Note. M: Mean; SD: Standard deviation; SEM: Standard error of mean; & CI: Confidence interval

Table 6. Relationship between quality of work assignments & modeling abilities of experimental class in off-line phase (n=48)

		Off-line work scores	Modeling scores (post-test)
Off-line work scores	Pearson sig. (2-tailed): n	1	.880**
			.000
	n	48	48
Modeling scores (post-test)	Pearson correlation	.880**	1
	sig. (2-tailed): n	.000	
	n	48	48

Note. **Correlation is significant at 0.01 level (2-tailed)

Changes to Experimental Class Students' Work Quality, Modeling Skills, & Biology Learning

To compare any statistically significant differences in the quality of students' hands-on learning work assignments between online and offline phases, *t*-tests were performed. The paired samples *t*-test results showed that the differences between the two phases of experimental students' work mean scores were statistically significant at the 0.05 level ($p=0.002<0.050$, see **Table 3**), and the differences between the two phases of students' modeling abilities mean scores in five aspects were not statistically significant at the 0.050 level ($p=0.881$, 1.000, 0.659, $0.605>0.05$).

However, students had statistically significant different mean scores on impact of the model as a learning tool ($p=0.011<0.050$). **Table 4** presents the results. According to the statistics of the biology scores in the final grades before and after the experiment in the experimental class, the average biology score of 75.13 after the experiment was significantly higher than the average biology score of 71.98, before the experiment ($p=0.017<0.050$, see **Table 5**). Thus, there is evidence that HLVA approach contributes to the improvement of students' biology learning achievement.

Relationship Between Students' Work Quality & Modeling Skills

In order to determine if there was any relationship between the quality of students' work and modeling abilities between two phases, correlation analysis was performed. The results indicated that there was a statistically significant positive correlation between the experimental class students' work assignment scores and their modeling ability scores ($r=0.880$, $p=0.000<0.050$) in the offline phase instead of during the online phase, which means that the higher the quality of offline hands-on learning work assignments, the higher the scores of modeling ability. **Table 6** presents the results.

Responses During Experimental Phase & Two Years Later

All students in the experimental class enjoyed HLVAs approach during the experimental phase. For example, 89.6% of students enjoyed the learning process, 93.7% students occasionally participated in hands-on science learning in their daily lives, 91.6% students felt a sense of accomplishment by completing the hands-on learning tasks, 89.6% students recognized that their creativity was stimulated, and 83.3% students believed that their hands-on skills were greatly improved.

Students shared on their questionnaires that it took at least one hour to finish each assignment, from conceptualizing to designing the model, and then recording the explanatory videos. Female and male students acknowledged that they enjoyed this learning method a lot, which also helped them develop an understanding of scientific concepts. They were also inspired by the models made by their student peers. One boy, Xiaojun, said he saw a fish model created using leaves, which was very "innovative." A girl, Xiaohong, shared that a cell model was "impressive and was very exquisite, clever, and had outstanding details." Another girl, Xiaohua, said that her hands-on skills still need to be strengthened and that she wants to learn how to use various tools for modeling.

As for the reasons why, some students did not actively submit their videos. Two out of five students said that they lacked enough time to make learning videos due to having to finish other class subjects' homework. For example, students Xiaozhao and Xiaoqian said "I had spent a lot of time on homework for other subjects and did not have time to make models and then record videos." Xiaosun said "I did not like doing such homework and did not understand what the assignment was." Xiaoli remarked on a feeling of isolation, "I did not do it because I did not have fun doing it alone." Xiaozhou said, "I did not dislike such homework, but I always forget to complete it." In addition, students shared that not completing the hands-on learning assignments on time adversely impacted their modeling skills, understanding of biological structures, and learning.

Two years later, a follow-up questionnaire was conducted with students from the experimental class after they went to traditional high school or vocational high school. A majority of students, 61.0%, were deeply impressed with the modeling process, while 39.0% students were impressed with this learning experience; 50.0% students were deeply impressed with manipulating models, while 39.0% were impressed with manipulating models; 53.0% students were deeply impressed with hands-on learning with video assignments, while 32.0% were impressed with it; 38.0% and 50.0% students believed that this learning process was very helpful and helpful for high school entrance exams, respectively; 47.0% and 44.0% students believed it was very helpful and helpful for high school learning; 72.0% students answered that they missed hands-on learning a lot while 29.0% missed it. Moreover, prior to this study, regarding students' experiences with making biological models and learning videos, 41.0% students made one, 22.0% students made two, 16.0% students made many, and the rest made none. With respect to whether their teachers at their current school use the hands-on learning and video assignment method, 65.0% students who answered said their teachers hardly used it in their biology teaching.

DISCUSSION

This study explored an HLVAs approach with students during and immediately following the COVID-19 pandemic. The COVID-19 pandemic intensified new changes in science learning, as online instructional videos became a core science learning resource. As Giannakos et al. (2015) pointed out, learning ecosystems are framed as the complex of living organisms in a learning environment (e.g., students, educators, and resources), and all their interrelationships in a particular unit of space (Breslyn & Green, 2022; Giannakos et al., 2015). Learning videos recorded by students, especially middle school students, are rarely valued, and there are limitations to teaching and learning science only in a virtual way (Kurtz, 2020). Thus, we adhered to embodied cognition theoretical perspectives and let students use readily available materials around them to create models, which served as learning tools, resources, and outcomes. We also designed and developed a learning work evaluation scale to quantitatively explore the impact of HLVAs approach on learning effectiveness. Specifically, we explored the impact of HLVAs teaching approach on students' learning quality, modeling ability, and academic performance. This study is consistent with the current hands-on science concepts advocated NGSS Lead States (2013) and the Chinese science curriculum standards (Ministry of Education of the People's Republic of China [MoE], 2022). Additionally, this study confirmed the usefulness of student models as learning tools, and the importance of students' embodied cognition in their learning of science.

Embodied Cognition in HLVAs Approach

The greatest learning gain for students came from the development of embodied thinking based on modeling and the explanation and videorecorded learning process when students demonstrated the inseparability of the body-mind-environment. From embodied cognition, an embodied learning paradigm suggests that actions, emotions, sensations, and environment can influence what is learned (Macrine & Fugate, 2022). To achieve the goal of understanding concepts and constructing propositional networks, students coordinated their bodies' sensory, motor, and nervous systems to construct knowledge, and other body systems were necessary for this to occur as well (circulatory, respiratory, etc.) and cannot be separated, as the systems interact with other systems to function. For example, students used their eyes as a visual sensor, hands in operating models or drawing diagrams, mouths in explaining the scientific principles contained in models, and brain and spinal cord cells were stimulated by multiple inputs to establish extensive connections. During the engagement process of the body-mind-environment, students fully immersed themselves in active learning. They could experience all the "events" related to learning biological concepts that they felt, heard, and saw. Moreover, they acquired information processing abilities and embodied cognitive thinking in learning such as image perception and thinking, text perception and thinking, speech perception and thinking, and comprehensive information learning and thinking. More importantly, they engaged in cognitive processes, as summarized by Bloom (1956), such as remembering, understanding, applying, analyzing, evaluating, and creating, among others.

Evidence of Effectiveness of HLVAs Approach

By conducting paired samples *t*-tests on the quality of students' assignments and biology scores of the experimental class students, the results showed that the quality scores of work assignments in the offline teaching phase was significantly higher than that in the online teaching phase, and there was a statistically significant improvement in students' academic performance. This indicates that the effectiveness of offline teaching was better than that of online teaching, which is consistent with the research results on the ineffectiveness of online learning during the pandemic (Hong et al., 2021). This finding indicates that for the student participants, the improved quality of learning cannot be separated from teachers' interventions.

The research results on students' modeling abilities are not as optimistic. There were no statistically significant differences in the total scores of students' modeling abilities between the pre-and-post tests, indicating that this teaching strategy has not improved the overall level of students' modeling abilities. As for potential reasons for these findings, on the one hand, the experimental intervention time was relatively short, and the development of students' modeling abilities and teachers' abilities with teaching modeling requires long-term training. Inadequate teaching strategies and insufficient guidance from teachers on student modeling could be other reasons for these results. However, there was a statistically significant difference in the dimension of modeling ability: the impact of models as learning tools between the pre-and-post tests, indicating that this teaching strategy has improved their understanding of models as learning tools. This result supports research on improving students' scientific abilities through modeling (Kim et al., 2015; Wang et al., 2021; Werner et al., 2017).

A positive relationship between students' work quality and modeling skills existed during the offline phase, which means that the higher the quality of offline hands-on learning work, the higher the score of students' modeling abilities. Whatever the reason, we should carefully and judiciously draw a conclusion from this finding that HLVAs approach with teacher intervention can improve the quality of students' learning work samples, partially promote the improvement of students' modeling skills, and significantly impact students' academic performance.

This study found that HLVAs approach can help improve students' biology grades, cultivate their interest in learning, and enhance their understanding of models as learning tools. In addition, the production of models can improve students' hands-on abilities and systematic thinking, and the production of videos can improve students' information literacy. In short, HLVAs contributes to students' comprehensive development. However, there are also difficulties in implementing HLVAs approach. The production of models and the recording and editing of videos requires an extensive amount of time, and there are also certain requirements for students' abilities. In this regard, teachers need to arrange the model production cycle reasonably, require students to report their teaching progress in stages, and provide timely guidance and assistance.

Impact of HLVAs Approach on Science Teaching

This study shows that regardless of the learning context, HLVAs approach is a teaching method that has a profound impact on students. Unfortunately, after entering high school, students did not have opportunities to use this method in school. Video has accelerated to become a learning resource that cannot be ignored and an important part of the learning ecosystem under the influence of the COVID-19 pandemic (Breslyn & Green, 2022). However, in the post-epidemic era, video can still be integrated into teaching. Therefore, questions should be further studied and explored, such as what are the factors that affect teachers' use of video during instruction, and how can videos be integrated effectively into teacher instructional design?

What is more, students are centered with HLVAs approach, while the teacher only serves as a guide and supervisor in this process. Students choose the materials and methods themselves for making the model, decide on the style of the model, and then make video explanations to express their understanding of the science knowledge throughout the process of completing the learning tasks. Each learner's operational process is different, and the depth of their understanding of knowledge naturally varies, so at this point, mutual sharing and learning become particularly important. Each student's video can become a learning resource for other students such that analyzing the quality of videos at different levels could help students with weaker abilities, and showcasing excellent videos is also a means of motivating all students to progress. In this way, children can also be teachers (Dewey, 1902; Tao, 1981; Zhou & Xiang, 2010); hence, we cannot ignore the educational factors contained in the videos created by students themselves and must be aware that if they were created and utilized, they could also become integral educational resources for peer-learning, feedback, and educational evaluation.

Embodied cognition helps us understand the role of action and experience in the learning environment (Kontra et al., 2012). It is worth noting that education is both in the classroom and outside the classroom, and good education should be integrated into daily life. Based on the theory of embodied cognition, we recognize the importance of model making for scientific learning, but it is difficult to complete in the classroom due to the limitations of time, space, and learning resources. Placing the model production outside the classroom allows students to choose materials from their daily lives, expanding the scope of learning resources, and turning life into a classroom (Dewey, 1916; Tao, 1981; Zhou & Xiang, 2010). Students' use of everyday materials for modeling and science learning also deserves further study.

Starting from the theoretical perspectives of embodied cognition, this study explores HLVAs approach that combines online teaching with hands-on, minds-on learning, utilizing materials readily available in the surrounding environment to create models and deepen the understanding of knowledge in biology learning. This model is still applicable in the post-pandemic era, combining science education with digital education based on online and offline modes, updating teaching methods, enhancing students' learning interests, and cultivating scientific literacy.

Current Implementation & Future Applications of HLVAs Teaching Strategy

At present, HLVAs teaching strategy continues to be used in middle school biology teaching, but the implementation time and place have changed. Teachers arrange HLVAs based on their teaching preferences, and some classes create models according to the content of the class and make models related to each lesson in the current lesson. Some classes, after completing a unit, select a specific class time for students to work together in groups to complete the models involved in the unit. Generally, when there is sufficient class time, the teacher arranges for students to complete them in class and records explanatory videos for students in the classroom because students are not allowed to bring electronic devices such as mobile phones into school.

Additionally, sometimes students are asked to use their out-of-class time to complete the assignments. At certain stages, students are required to briefly report their progress, and the teacher provides guidance. The first author of this paper also participated in the research project for socio-scientific issues learning (SSI-L). She applied HLVAs to the school-based course, SSI-L, offered by the school, which is held once per week. The activity content of each class was created by students themselves (such as the DNA double helix structure model, cell model, chromosome model, and seed structure model) and described by students.

From the questionnaire results two years later, it can be seen that teachers are somewhat hesitant to continue implementation of HLVAs approach. The reasons can be attributed to three aspects: first is the lack of upper-level design. Although the curriculum standards repeatedly emphasize the importance of exploratory practice and the importance of models as learning tools (MoE, 2022), they overlook the specific implementation strategies of teaching. Second, there is a lack of school support, and the conditions that schools can provide for hands-on learning are limited. For example, schools do not allow students to bring mobile phones, and teachers have limited video recording equipment available. Finally, teachers are still developing awareness of hands-on learning and occasionally feel that it is too time-consuming to navigate and implement.

Change can start with the teacher. HLVAs approach is not only about recording model-making videos, but it is also about the problems that students encounter and the ideas and methods for solving them. By engaging in hands-on modeling tasks, students can more intimately grapple with perplexing problems. By solving real-world problems, students' learning can be meaningful. HLVAs achievement can also be an important component of portfolio evaluation. We will continue to accumulate experiences in practice and continuously improve HLVAs teaching strategies. When it is sufficiently comprehensive, reasonable suggestions can be made to the curriculum standard writing group. If HLVAs approach is included in the curriculum standards, it will have greater positive impacts.

Recommendations

This study provides a teaching approach for effective biology teaching in various educational contexts, which extended from online to offline, utilizing video recording technology, where students engaged in embodied learning modeling activities. Future research is needed to examine how this teaching approach affects students' learning from embodied cognition perspectives. Many studies tend to combine hands-on learning with computer simulations (Wang et al., 2021), online modeling tools (Kim et al., 2015), excel-based modeling (Malone et al., 2017), 3D printing (Werner et al., 2017), or video-based material developed during COVID-19 (Breslyn & Green, 2022). Importantly, students learn from interactions with materials around them.

New technologies may call for new forms of coordination (Ma & Nickerson, 2006), but we believe that for middle school students, teaching with everyday materials to construct physical models and learning scientific knowledge during the process of operating models have special significance. One student with autism said that he sometimes did not understand the learning tasks, and one student with an intellectual disability said that it was not fun to do the task alone. These findings require increased efforts to ensure that science instruction is more inclusive for neurodiverse learners and students with physical disabilities, such as frequent checks for understanding, multiple means of representing and expressing information, and engagement that fosters collaboration and community, consistent with the universal design for learning principles (CAST, 2018). Through special education embodied design that utilizes guiding principles in embodied learning (Tancredi et al., 2022), learning accessibility and inclusive educational design is reimagined and also deserves further research.

This study provides an effective teaching model for middle school science education and provides insights for future research on the role of models and modeling in science education. Future studies can explore the role of peer review, discussion, and collaboration during the process of model construction, refinement (with multiple iterations), and explanation, as well as the use of the modeling videos created by the students for students' learning. Foregrounding student work, agency, and pride is critical. Overall, hands-on, embodied learning experiences can provide a foundation for scientific learning and more meaningful, impactful instruction.

Author contributions: QJ: conceptualization, methodology, resources, validation and writing – original draft; **RZ:** conceptualization, project administration, methodology, writing – original draft and funding acquisition; **XD:** investigation, formal analysis, writing – original draft and validation; **JT:** supervision, resources and writing – review & editing; **XL:** supervision and writing – review & editing; **CC:** resources, visualization and writing – review & editing. All authors agreed with the results and conclusions.

Funding: This study was financially supported by the Chunhui Cooperative Scientific Research Project (No. HZKY20220509 - 202201024).

Ethical statement: The authors stated that principles of research ethics were strictly adhered to at all phases of this study. Participants were informed about their participation in this study. Researchers fully respected students' choice of participation & privacy of their information & responses. Participants were given pseudonyms to ensure anonymity and privacy.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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