CHINESE PRACTICE OF RESEARCH-BASED LEARNING IN BASIC PHYSICS EDUCATION

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Abstract

The construction of physics education courses based on research-based learning has become the focus of curriculum reform in many countries. In China, situational and experimental teaching methods were encouraged by the new curriculum standards, so it is necessary to introduce research-based learning in basic physics teaching. In this study, the specific implementation and case design of research-based learning were explored and practised. Using Newton's second law as an example, the application of the research-based learning model in senior-high school physics education was discussed, and countermeasures for implementing research-based learning were proposed. The results show that the application of research-based physics learning can effectively improve students' scientific skills and learning outcomes, and therefore suggest that high school physics teachers draw on this model when implementing research-based learning.

Keywords: *research study, high school physics, Newton's second law, case design*

1. INTRODUCTION

Research based learning is an activity in which students choose research topics from social life based on independent exploration under the guidance of teachers, and take the initiative to acquire knowledge and solve problems in a way similar to scientific research (Wang, 2020). The research-based learning model fully reflects the "Student-centered" educational philosophy proposed by American educator John Dewey and Swiss educator Jean Piaget, and it helps to cultivate talents who are not afraid to question authority and are brave enough to innovate (Estuhono et al., 2019). Research-based learning is also a new curriculum form under the new curriculum philosophy of Chinese high schools. It is popular among front-line teachers and students for its openness, exploratory nature and practicality.

Physics is a science based on experimental research. The introduction of physical concepts and the acquisition of laws are both dependent on research. Therefore, conducting research-based learning activities in physics teaching, so that students can understand and apply the corresponding physics concepts and laws, is not only a "people-oriented" and "student-centered" educational need, but also reflects the essence of physics teaching (Liu and Li, 2011). Physics is widely used in production technology and is closely connected to social life, which provides a wide space for research based learning. The process of integrating research-based learning activities into physics teaching is also a process of reforming physics teaching methods. In the process of reforming both "teaching" and "learning", students will be able to understand physics knowledge, have a certain quality of science and creative consciousness, and adapt to the needs of the current social development (Fatade et al., 2013).

Newton's laws of motion are the theoretical basis of classical mechanics as well as the focus of high school physics teaching. Regarding Newton's laws of motion, China's requirement in the old curriculum standard was "explain relevant problems in life", while the requirement in the new curriculum standard has changed to "explain relevant phenomena in manufacturing and daily life as well as solve relevant problems", adding the expression of "solve relevant problems", emphasizing the application of Newton's laws in manufacturing practice and the social impact of physical knowledge. In addition, the new version of the curriculum standards has added a chapter on scientific research, which also provides policy support for research and practice of research based learning.

Research based learning is a way of teaching to develop students' innovative spirit and practical ability. The introduction of research-based learning in modern physics teaching, where teachers guide students to learn by practice, helps develop students' subject literacy and independent learning skills (Usmeldi,

2016). This paper explored and implemented research-based learning in high school physics teaching, taking the conveyor belt problem in the application of Newton's second law as an example, guiding students to discover the phenomenon of objects sliding on a conveyor belt to form traces in their lives, and investigating it by constructing physical models and theoretical calculations. The whole process of research based learning teaching from case design to classroom implementation as well as from student experiments to demonstration experiments has been formed, fully reflecting the student-centered view of education. The results show that the application of research-based physics learning can effectively improve students' science skills and learning outcomes, and it is recommended that high school physics teachers adopt this model when implementing research-based learning.

2. TEACHING METHODS

2.1. Analysis of students' learning situation

This course is a new lesson for the conveyor belt scratching problem, based on the motion and force characteristics of the conveyor belt problem that students have already learned. Through the pre-study of the application of Newton's laws, students have a preliminary understanding of the relationship between force and motion, and students have been able to use Newton's laws of motion to handle simple conveyor belt problem scenarios. Problems of individual students include: lack of precision in motion analysis; lack of accuracy in friction analysis; lack of experience in life observation and difficulty in establishing multiple life situations.

Conveyor belt problems are difficult for students because they have previously studied motion relative to the ground, i.e., with the ground as the reference system, which is relatively stationary. The students took it as a truth that "friction hinders the motion of an object and is in the opposite direction of the object's motion", while breaking the mindset of students was the key to solving conveyor belt motion problem. This lesson is facing the students from Chengdu No. 7 Middle School, who come from the best high schools in southwest China and have a solid foundation in mathematics and science, so the analysis of friction and the properties of motion will not be explained in detail, and the typical physical models were explained by the students. The focus of this lesson is on good qualitative analysis and quantitative calculation of related problems, so that students can identify the advantages of using the image method to solve problems.

2.2. Teaching approach

Based on the above analysis of the learning situation, this research-based learning course practice mainly adopts three teaching methods: experimental method, situational teaching method and discussion method. The specific implementation methods in the lesson are as follows.

2.2.1. Experimental method

Experiments in research based learning course practice include pre-course inquiry experiments, in-class student experiments, and teacher demonstration experiments. Before the course, an inquiry task was assigned to students. The specific requirements were: every three students formed a group to find the phenomenon of objects producing sliding traces on the conveyor belt in life, and made a video. From the results of the exploration, students observed the relative sliding between the object and the conveyor belt in the smoother surface of the conveyor belt, such as the treadmill at home, the security conveyor belt in the subway station, and the elevator handrail in the mall. Based on the recorded videos, personalized videos material were formed by the students through editing and dubbing, which enriched the teaching and added interest into the lesson.

Student experiments during the lesson originated from the abstraction and reproduction of the students' pre-course inquiry experiments (Prahmana and Kusumah, 2016). As shown in Fig. 1, the horizontal conveyor belt was first placed on the table, and a loop of white silk belt was placed on the conveyor belt to reduce friction. In a square block of six surfaces were taped by transparent tape, any one of the block's surface will be stained with red ink. Then released the block on a horizontal moving conveyor belt

without initial speed, observe whether the block can leave obvious scratches on the conveyor belt, and measured the length of the red ink marks on the conveyor belt.

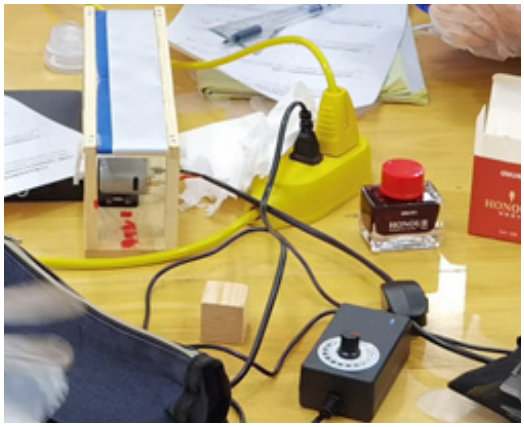


Fig. 1. Student experimental equipment.

The purpose of the teacher's demonstration experiment was to obtain the kinetic friction factor, an important parameter for studying the motion of objects on a conveyor belt. The acceleration of the object was measured using the acceleration sensor in the iPhone and the software called Phyphox in iOS to obtain the coefficient of kinetic friction. It was implemented by turning on the conveyor belt as well as the data collection switch in the cell phone software and releasing the cell phone on the conveyor belt without initial speed. The acceleration value was read by observing the acceleration data on the cell phone interface, and then the coefficient of kinetic friction between the block and the conveyor belt was obtained based on the force analysis of the object and Newton's second law (Eq.1).

$$\mu mg = ma \tag{1}$$

where μ is the coefficient of kinetic friction between the block and the conveyor belt; m is the mass of the block, kg; g is the acceleration of gravity, m/s^2; a is the acceleration of the block, m/s^2.

2.2.2. Situational teaching method

According to the students' preliminary experimental research results, the teaching process of research based learning was divided into four stages, each of which was taken from the life situations created in the students' experimental inquiry, thus leading to four physical models of conveyor belt problems corresponding to the situations in the course.

(1) The motion of a block without initial velocity on a horizontal conveyor belt rotating clockwise. Based on a group of students using cling film to make their own horizontal conveyor belt and release the Rubik's Cube without initial velocity, the most basic model of block motion on a horizontal conveyor belt rotating clockwise without initial velocity was abstracted.

(2) The motion of a block on a counterclockwise rotating conveyor belt with a reverse initial velocity. According to a group of students throwing iron blocks onto a treadmill with counterclockwise rotation, abstract the model of the motion of a block on a counterclockwise rotating conveyor belt with a reverse initial velocity, and the initial velocity of the block was greater than the speed of conveyor belt.

(3) The block's motion after being released without initial velocity at the top end of an inclined conveyor belt that rotates counterclockwise. Based on an inquiry case in which a group of students released an object from the upper end of a raised inclined treadmill without initial velocity at one end and eventually slid away from the treadmill, a model of the object's motion after being released without initial velocity at the upper end of a smoother ($\mu < \tan\theta$) counterclockwise rotating inclined conveyor belt was abstracted.

(4) The motion of a block on a horizontal conveyor belt with uniform acceleration. According to the phenomenon that students put the object first and then turn on the power of the conveyor belt during the experiment, the model of the object moving on the horizontal conveyor belt with uniform acceleration was abstracted.

2.2.3. Discussion method

The discussion method in research based learning was mainly embodied in student experiments. Firstly, students would discuss the results of the inquiry experiments outside the classroom before the lesson, and apply Newton's second law to perform the corresponding analytical calculations to form the inquiry results of the experiments conducted. Secondly, as shown in Fig. 2, during the students' experiments, sufficient discussion time was left to guide students to calculate the theoretical value of scratch length produced by red ink on the conveyor belt, analyze the causes of the difference between the theoretical and measured values of the scratch length, and explore the reasons leading to the differences in the measured values of the scratch length in different groups of experiments.



Fig. 2. Student experiments and discussions.

2.3. Teaching objectives

Through a teaching approach using research-based learning, the following teaching objectives are expected to be achieved in this lesson.

(1) Knowledge and Skills: Students can use Newton's second law to analyze the force and motion of the block before and after the state of common velocity, understand the solution to the conveyor belt trace problem, understand the difference among the relative displacement, scratch length and relative distance between the conveyor belt and block, and can use the *v-t* image to solve the relative displacement problem.

(2) Process and Methods: Through the observation of various phenomena in life and experimental results, the origin of the conveyor belt scratches was derived. Guide students to experimentally obtain the block scratches on the conveyor belt and verify the scratch length by calculation.

(3) Emotional attitude and Value: To develop students' ability of experimental inquiry and practical problem solving (Rumahlatu and Sangur, 2019).

3. TEACHING PROCESS

3.1. New lesson introduction

In the introduction phase of the course, the teacher led students to discuss the phenomenon that the middle of the security conveyor belt at train and subway stations is smoother and brighter than the sides,

and led them to conclude that the cause of this phenomenon is friction from relative sliding. It means that the relative sliding will occur between the conveyor belt and the luggage, and the long time relative sliding will make the middle of the conveyor belt a little brighter than the two sides.

Thereafter, two experimental videos of students' research study results were shown, containing examples of successfully observed and unobserved phenomena of relative motion between objects and the conveyor belt. As shown in Fig. 3(a), the relative motion was successfully observed in the case of a student releasing the Rubik's Cube without initial velocity on a horizontal conveyor belt made from cling film.

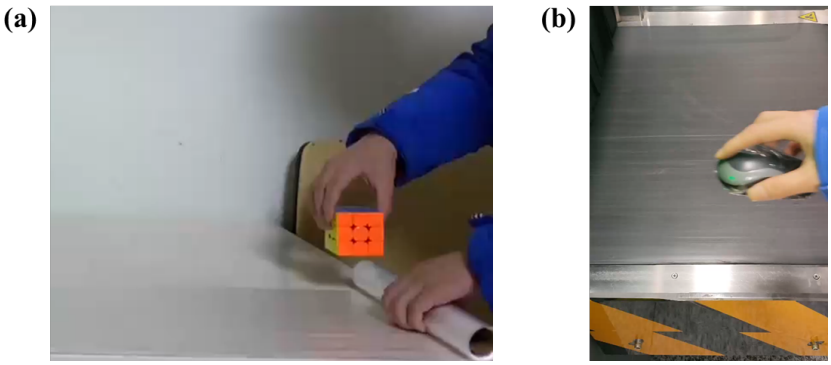


Fig. 3. Research case of the relative motion between the object and conveyor belt: (a) successfully observed; (b) not observed.

As shown in Fig. 3(b), the case in which no relative motion was observed is the case in which the student released the mouse without initial velocity on the security conveyor belt at the subway station. To help students find the problem in the experiment, the teacher showed a video of a successful experiment taken by another group. Finally, guide the students to think about the reason why no obvious scratches were caused is that the block has a larger friction factor with the conveyor belt.

3.2. Student experiments

Using the experimental apparatus shown in Fig. 1, students were organized in groups and measured the scratch length left by the block dipped in red ink on the horizontal conveyor belt wrapped with white satin, i.e., to simulate the scratch left by the block moving on the horizontal conveyor belt without initial velocity, and try to apply Newton's laws of motion to verify in theory.

The results show that significant scratches can be seen in the experimental results of all groups. As shown in Fig. 4, the total length of the red ink traces on the conveyor belt measured by each group of students with a scale varied from a maximum of 8 cm to a minimum of 3 cm. This is due to that the groups set the stepless transmission on the conveyor to different gears, making different speeds of the conveyor.

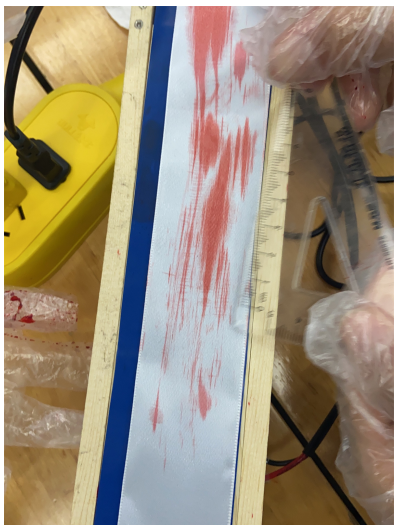


Fig. 4. Student experiment results.

The problem can lead students to think about the factors affecting the scratch length, and use Newton's second law to deduce the scratch length between the conveyor belt and block as shown in Eq. 2, expecting to verify the reasonableness of the experimental results with the help of theoretical calculations.

$$l = \frac{v^2}{2\mu g} \tag{2}$$

where, l is the scratch length, m; μ is the coefficient of kinetic friction; v is the conveyor belt speed, m/s; g is the acceleration of gravity, m/s^2.

3.3. Demonstration experiments

The values of conveyor belt speed and kinetic friction factor are lacking in the process of verifying the experimental results based on Newton's second law. According to the factory specifications of the speed regulator connected to the conveyor belt, the maximum speed of the conveyor belt was known to be 0.4 m/s. To verify the experimental results, the coefficient of kinetic friction between the object and the conveyor belt needs to be measured.

To this end, the iPhone was released without initial velocity on a larger horizontal conveyor belt in an instructor-demonstrated experiment during the lesson. The acceleration of the phone was measured with the help of acceleration sensor in the iPhone and the Phyphox software in iOS, and then the coefficient of kinetic friction was obtained from Eq. 1. As shown in Fig. 5, the first peak in the acceleration profile obtained by Phyphox corresponds to an acceleration magnitude of about 2 m/s^2.

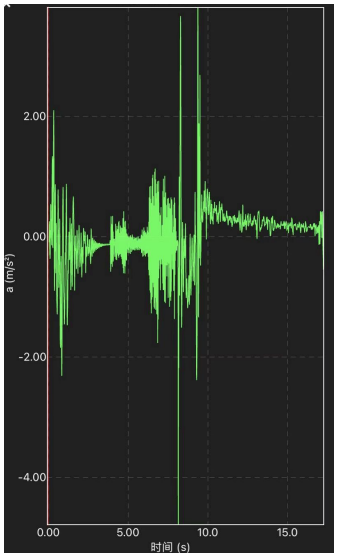


Fig. 5. Acceleration of the phone measured by Phyphox.

According to the force analysis of object, the coefficient of kinetic friction is about 0.2. Ask students to bring the above data into Eq. 2 and calculate the theoretical value of the scratch length as 4 cm. By subtracting the maximum scratch length from the object length, it can be considered that the measurement results are roughly in line with the theoretical calculation within the permissible range of error.

3.4. Construction of theoretical model

The physical model for analyzing the scratching problem on the conveyor belt using Newton's second law was constructed based on the life situations in the students' inquiry experiments. In the teaching process of each scenario, the results of the inquiry experiment and the students' calculation results were displayed, and the calculation results of multiple methods were selected for screen projection, with emphasis on guiding and explaining the image method to solve the relative displacement. It is clear that the scratch was related to the relative displacement, and the *v-t* image is a powerful way to calculate the scratch length.

3.4.1. The motion of block without initial velocity on a horizontal conveyor belt rotating clockwise

In the experimental apparatus shown in Figure 6(a), the Rubik's Cube was released without initial velocity on a horizontal conveyor belt made by students using cling film, thus abstracting the most basic model of a block without initial velocity moving on a horizontal conveyor belt rotating clockwise, as shown in Figure 6(b).

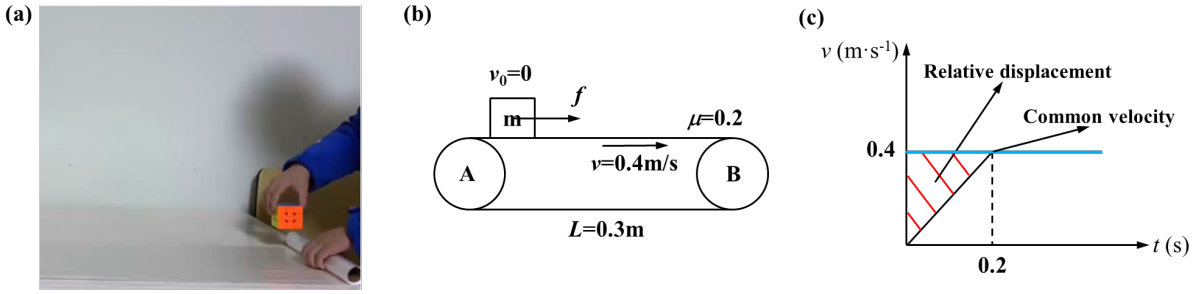


Fig. 6. Motion of a block without initial velocity on a horizontal conveyor belt rotating clockwise.

According to the plotted *v-t* image shown in Figure 6(c), guide the students to realize that: the scratch is no longer produced after the block and conveyor belt have a common speed, the value of relative displacement is equal to the area of the shaded triangle, and the displacement of block relative to conveyor belt is to the left, the scratch length and relative displacement are equal at this time.

3.4.2. Block motion with counterclockwise rotation of the conveyor belt with reverse initial velocity

In the experimental apparatus shown in Fig. 7(a), students throw the iron block onto a treadmill that rotates in the reverse direction, thus abstracting the motion model of a block that has a reverse initial velocity with counterclockwise rotating conveyor belt, and the initial velocity of block is greater than the speed of conveyor belt, as shown in Fig. 7(b). Students analyze the motion and forces on the object by observing the phenomenon and calculate the scratch length left by object on the conveyor belt.

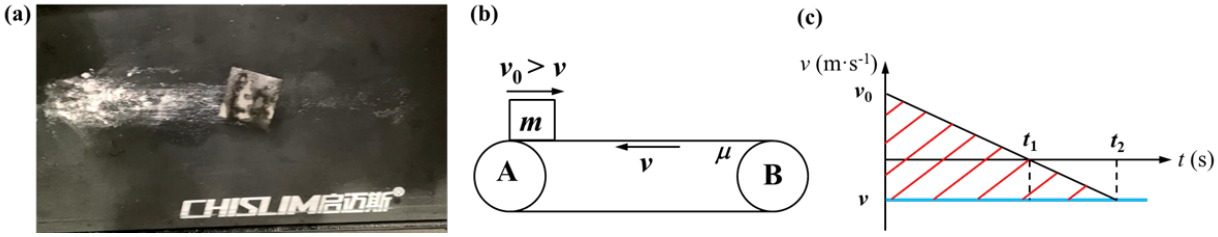


Fig. 7. The block motion with counterclockwise rotation of conveyor belt with reverse initial velocity.

In the experimental situation, the block is always subject to friction in the left direction, so that it first do uniform deceleration, the speed is reduced to zero and then reverse acceleration, and finally has a common speed with conveyor belt. Select the positive direction to the right and guide students to draw the corresponding *v-t* image as shown in Fig. 7(c), the shaded area is the relative displacement value in the time period from 0 to t_2. Since the direction of relative displacement is to the right in both the 0 to t_2 and t_1 to t_2 time periods, the scratch length of object on the conveyor belt is consistent with relative displacement.

3.4.3. Block motion after being released without initial velocity at the top end of an inclined conveyor belt rotating counterclockwise

In the experimental apparatus shown in Fig. 8(a), students raised one end of the treadmill to tilt it, released the object from the top of the treadmill without initial velocity, and observed that the object kept accelerating until it slid off the conveyor belt. Block motion with no initial velocity on a counterclockwise rotating inclined conveyor belt was thus abstracted as shown in Fig. 8(b).

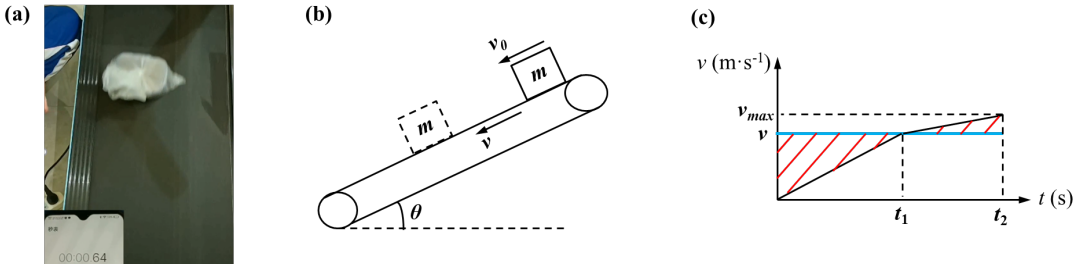


Fig. 8. Block motion after being released without initial velocity at the top end of an inclined conveyor belt rotating counterclockwise.

According to the force analysis of object, listed the Newton's second law along the direction of the slope (Eq. 3), it can be seen that the object has been uniformly accelerated motion until it has a common speed with the conveyor belt. Since the surface of the treadmill used was relatively smooth, even if the

conveyor belt was stationary, the object would slide on its own after being placed on it ($\mu<\tan\theta$). Therefore, after the object and the conveyor belt reach a common speed, they cannot move together at a uniform speed. As the frictional force reverses, but the combined force remains downward along the incline, the object continues to accelerate downward with a smaller acceleration (Eq. 4).

$$mg\sin\theta+\mu mg\cos\theta=ma \tag{3}$$

$$mg\sin\theta-\mu mg\cos\theta=ma \tag{4}$$

where m is the mass of object, kg; g is the acceleration of gravity, m/s^2; θ is the inclination angle of conveyor belt; μ is the coefficient of kinetic friction; a is the acceleration of object, m/s.

Finally, students were instructed to draw the *v-t* images of the conveyor belt and block as in Fig. 8(c). The difference between the relative displacement , scratch length and relative distance between the block and conveyor belt under this model is a key issue for students to identify. Therefore, the problem will be given to students to discuss in groups, through the teacher's questions, on the basis of the identification of three physical concepts, guiding students to the following conclusions: because the direction of relative displacement before and after the common speed is opposite, so the value of the displacement of object relative to the conveyor belt should be the difference between the two shaded areas; because the object in the conveyor belt reference system shows the characteristics of reciprocal motion, the scratch of former section will be covered by the scratch of latter section, so the scratch length should be the area of larger piece of shadow; finally, the relative distance between the object and conveyor belt is the sum of relative displacement of two sections.

3.4.4. Block motion on a horizontal conveyor belt in uniform acceleration

As the experimental apparatus shown in Fig. 9 (a), there exists a phenomenon of students in the inquiry experiment to put the rechargeable battery on the treadmill first and then open the treadmill, when the conveyor belt has acceleration. This abstracts the motion model of the block on a horizontal conveyor belt with uniform acceleration, as in Fig. 9(b). To make it more convenient for students to use Newton's second law for theoretical calculation, the model is further generalized. In order to keep the rechargeable battery from falling off the treadmill, it is assumed that the treadmill first accelerates with an acceleration larger than μg a for a period of time and then immediately decelerates with the same size of acceleration for the same amount of time, just enough to transport the rechargeable battery with zero initial velocity from point A to point B. Ask students to calculate the relative displacement of rechargeable battery on the treadmill, the scratch length and the relative distance respectively.

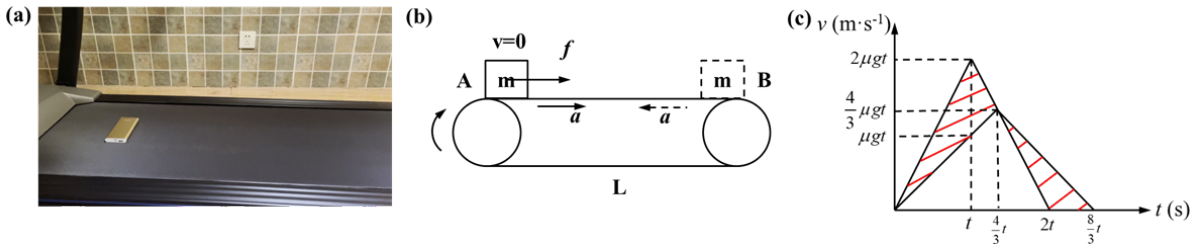


Fig. 9. Block motion on a horizontal conveyor belt with uniform acceleration.

The teacher guided the students to calculate independently and showd the students' results. The problem is challenging and therefore prone to incorrect answers. At time t, the block's velocity was μgt, which was less than the speed of the conveyor belt, so the co-velocity should occur during the deceleration of conveyor belt. Therefore, the acceleration of block and conveyor belt are different after the co-velocity, so they cannot maintain the co-velocity. As shown in Figure 9(c), based on the correct drawing of image, students were further guided to clarify the difference between relative displacement, scratch length and relative distance between the conveyor belt and the object in the scratch coverage problem.

4. DISCUSSION

4.1. Teaching effectiveness of research based learning

In the application of Newton's laws of motion, the conveyor belt problem was selected for research study practice. Conveyor belts have a wide range of applications in production and life, from which the conveyor belt model is one of the most classic models of high school physics. Conveyor belt problems are based on real physical phenomenon, which can train students' scientific thinking and relate to science, production and life reality, thus this type of problem is vital. The conveyor belt can be either a separate proposition or linked to electric field, magnetic field, frictional work, heat generation, etc. It can be said that the conveyor belt model has a very important place in high school physics teaching. This model is important for force analysis, motion process analysis, and the training and establishment of students' physical thinking. Integrating Newton's laws of motion, kinematic formulas, work and energy, etc. can be a good exercise for students' comprehensive analysis and logical thinking skills.

This lesson fully integrated students into the course through pre-class inquiry experiments with the help of a research-based learning approach, and unfolds the lesson in the order of the four contexts from inquiry experiments, enabling students to actively explore relevant questions and all levels of students can actively participate in the discussion. From the students' responses in the lesson, except for the last scenario, which corresponds to the motion model of a block on a horizontal conveyor belt with uniform acceleration, the students were able to grasp the model quickly and answer the corresponding questions correctly (Nursofah et al., 2018). According to the students' mastery of Newton's second law, the classes that went through the research study had better understanding of this module in the same type of classes.

4.2. Student-centered education philosophy

Research based teaching practice fully reflects the concept of student-centered education, which is reflected in: (1) four situations in the lesson were narrated by the corresponding group of students in pre-class inquiry; (2) each student was substituted into situation through student experiments; (3) generalized model was handed over to students for handling and explanation using inquiry project.

At the end of the lesson, the teacher led the students to discuss and shared the applications of conveyor belt scratching in production and daily life. The teacher introduced a high-resolution in-situ real-time friction energy dissipation measurement system recently developed by the State Key Laboratory of Tribology in Tsinghua University, one of the top academic institutions in China. The principle of this system was to create scratches between the object to be measured and the conveyor belt, and with the help of a series of devices, to accurately measure the energy loss during the process of creating the scratches. For accurate measurements, the entire experiment needs to be conducted in a vacuum environment and the surface of conveyor belt needs to be made of a super-slip material with a kinetic friction coefficient of about a few parts per thousand to enable such an experiment. Because Tsinghua University's tribology research is now world-leading, telling this story sets a life goal for students to enter such level of labs to challenge the frontiers of science.

5. CONCLUSIONS

This research based learning practice took the application of Newton's second law as an example, the application of research based learning in high school physics education was discussed, countermeasures for implementing research based learning were proposed, and the specific implementation and case design of research learning were given. Four types of conveyor belt scratching problems were solved using Newton's second law based on each of the four scenarios in the student research study results. Through experimental teaching and in-class discussions, students were guided to clarify that the key to the conveyor belt problem was to determine the direction of frictional force, and the *v*-*t* image was the best method to analyze the scratching problem of an object on the conveyor belt. The results show that the application of research-based physics learning reflects the philosophy of student-centered education, which can effectively improve students' learning interest and effectiveness, and we suggest that high school physics teachers should learn from this model when implementing research-based learning.

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