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THE MEASURING INSTRUMENT OF PRIMITIVE PHYSICS PROBLEM FOR UPPER-SECONDARY SCHOOL STUDENTS: COMPILATION AND EXPLORATION

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Abstract. *Problem solving is considered one of the most critical competencies for life. However, many students may perform well in school yet cannot transfer the skills they learned in school to solve real-world problems, especially in science education. This study discusses the characteristics of the problem from the physics education perspective, based on Problem Representation Theory, and proposes a new type of problem: The Primitive Physics Problem. Moreover, the significance and contribution in promoting students' physics problem-solving ability, both theoretical and empirical, are described. Then the study develops a set of instruments that was tested on 811 students in 12th grade from 10 upper-secondary schools in China. The results showed that the new instrument had good reliability and validity. The promising application in the instruction of the Primitive Physics Problem and in measuring upper-secondary school students' problem-solving ability of the instrument is discussed.*

Keywords: *primitive physics problem; problem solving; problem representation theory; assessment instrument.*

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Introduction

"All life is problem solving," as Popper (1999) said. It is widely regarded that problem solving is the most significant cognitive activity in daily life and career development. There are countless problems to be solved in everyone's life, such as, how to divide one's time into various types of work, whether to go to the gym or read on one's own for relaxing. All situations share a familiar pattern: there are a target state and a current state, and one needs the transition from the current to the desired state. Succeeding in the transition is called solving a problem, which often gets meaningful rewards, such as self-worth, valuable feeling. Solving real-life problems has two significances: intellectual and social-cultural values (Jonassen, 2000).

Since the capability of problem solving is vital in a world full of uncertainty, it becomes an ambitious goal for educators to strive for. As Gagne (1970) stated, the core goal of education is to cultivate individuals' thinking abilities, to train them to use the power of rationality, and to become better problem solvers. As a higher-order cognitive skill, the capability of problem-solving is considered the most critical learning outcome for life by most psychologists and educators (Zoller et al., 1995; Zoller, 2000). Nowadays, it has been regarded as a central objective of education in many countries. For example, countries participating in PISA (the Program for International Student Assessment) focus on a 15-year-old's ability to use knowledge and skills to meet real-life challenges and problem-solving competencies.

The series of studies are helpful to clarify how to cultivate individuals' capacities to deal with challenges in life for future learning, effective participation in society, and individual development (Lesh & Zawojewski, 2007). Research about developing problem-solving ability started as early as 50 years ago (Garrett, 1986), and it involves many topics in education, such as

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instruction, cooperative learning, experienced and inexperienced problem-solvers. However, it was found that students with high achievements in school are often unable to apply what has been learned in class to daily life, especially for science. Moreover, many higher-level students' problem-solving skills are inadequate, and the efforts to improve their ability to solve problems are not enough (Reif, 2010; Redish et al., 2006; Van Heuvelen, 1991). Thus, researchers need more effort, multi-angle, and suggestions for promoting students' problem-solving ability.

In this study, a new type of problem named primitive physics problem is introduced, which places the focus on physical facts and phenomena, the basis of physical sciences, with little abstraction, unlike typical textbook problems. In doing so, primitive physics problems require students to be creative in constructing the abstraction themselves, along with combining real-life scenarios with knowledge they learned in class. Hence, primitive physics problems can be an important tool to promote students' critical thinking and problem-solving skills. Here, the characteristics of primitive problems are examined from the physics perspective and the problems' characteristics and the critical representations of problem-solving are analyzed. The significance and contribution of primitive physics problem are explored in promoting students' problem-solving ability, both theoretically and empirically. In theory, the proposed problem's unique value and essential difference from other types of problems are discussed. Empirically, a set of instruments is developed with good reliability and validity to obtain the preliminary empirical evidence to support the idea that this type of problem promotes students' development of problem-solving skills.

Literature Review

Two kinds of factors influence problem solving, including external factors involving the essential characteristics of a problem and internal factors concerning the problem solver, like personal pre-knowledge, pre-understanding, and primary strategies. According to this framework, the reasons limiting students' problem-solving performance in education are: firstly, as an external factor, the types of problems students encounter in school and life are very different; secondly, as an internal factor, students have difficulty in improving from novice to expert in different problem contexts. As follows, the characteristics and types of the problem in physics education and then the characteristics of the cognitive representation of physics problem solving are summarized.

Problems in problem solving

Researchers proposed many different definitions with various perspectives, such as psychology, epistemology, methodology, logic, information theory, artificial intelligence, and so on. Some researchers define a problem as "an obstacle or a kind of difficulty", "a situation that people have no idea what to do to get the ideal goal when he or she wants to get it" (Newell & Simon, 1972), some are "a gap between a given state and a goal state" (Hayes, 1989; Wheatley, 1984), some are "a situation which people do not know how to deal with" (Reys et al., 1998). From these definitions, it can be concluded that a problem is a dynamic system consisting of expectations (goal pursuit), givens and obstacles, and a situation in which there is no direct, obvious method to follow. It has these characteristics: "undesirability," "concern," "difficulty," and "solvability". Based on the understanding of the characteristics of a problem, problems are divided into different categories. Among them, well-structured and ill-structured problems are the most common classification, which also distinguishes precisely the problem students face in school and life.

Well-structured and ill-structured problems

Between well-structured and ill-structured problems, the most significant difference is shown on the continuum of structuredness (Jonassen, 1997, 2000; Newell & Simon, 1972; Voss & Post, 1988). It is worth noting that structuredness represents a continuum rather than a dichotomy variable (Jonassen, 2010). The problems students encountered in formal educational contexts are mostly well-structured, typically found in textbooks and tests. Well-constructed problems consist of "a well-defined given state, a known goal state, and a constrained set of logical operators" (Greeno, 1980), in which there are all the pieces of information needed to solve the problem. For well-structured problems, a limited number of rules and principles must be applied, organized in a predictable and prescriptive way, with correct and convergent answers, and there is a preferred, prescribed solution process (Wood, 1983). On the other hand, the problems encountered in life and career are mostly ill-structured. Different from the well-structured problems, one or more essential elements needed to solve the problem are unknown in ill-structured problems (Wood, 1983); there are multiple solutions, solution paths, or no solutions at all (Kitchner,

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1983). Because of multiple criteria for evaluating solutions to ill-defined problems, learners are not sure what concepts, rules, and principles are needed and how they are organized, and learners usually need to make judgments and express their personal opinions or beliefs about the problem (Meacham & Emont, 1989).

Whether the strategies to solve the two types of problems are the same or not and whether they can be transformed, the research results are inconsistent. Some researchers believe that the strategies to solve problems are transferable between well-structured and ill-structured problems from an information-processing perspective, which is based on the assumption that the process used to solve the two kinds of problems is the same (Simon, 1978). However, some researchers find different ways for people to solve well-defined problems and ill-defined problems. (Cho & Jonassen, 2003; Dunkle et al., 1995; Hong et al.,2003; Jonassen & Kwon, 2001). It seems that well-structured and ill-structured problem solving involves significantly different cognitive processes (Jonassen, 2010).

Types of problems in physics

In physics education, three types of problems have been discussed: Practice problems or exercise, Context-rich problems, and Real problems.

Practice problems or exercise. It is suggested that practice problems are the typical textbook problems, which are also called standard problems by Maloney (1994). The essential characteristic of the type of problem is the idealized objects, which are usually not related to realities. In this kind of problem, the gap between goal states and initial states is eliminated. This kind of problem refers to a thorough knowledge of facts and procedures but excludes executing. When the textbook problems are to be solved, students are required to recall, comprehend, and apply specific rules or principles (Henderson, 2002), make sense of the necessary process to reach the goal, and execute the procedures like finding equations and plugging data. Besides, students do not experience the fruitfulness of possessing problem-solving frameworks.

Context-rich problems: They are also called "case study problems." They are defined as "stories that include a reason for calculating specific quantities about real objects or events" by Heller and Hollabaugh (1992). They are more realistic and related to students' life compared with practice problems. Context-rich problems are designed to improve students' problem-solving skills. When students solve this kind of problem, the typical approach is no longer feasible. The common characteristics of these problems include: (a) making reasonable assumptions may simplify the problems; (b) not including complete information for solving a problem or containing redundant information; (c) variables are not always clear and definite.

Real or true problems: The definition of them is the same as mentioned above, referring to the general problem.

Based on the primary problem framework, along a continuum from well-structured to ill-structured, it is found that practice problems or exercises are well-defined. By contrast, real problems are most ill-defined, and the context-rich problems fall between. As many researchers state it is hard to find the well-defined problems that contribute to fostering students' conceptual capacity (Byun & Lee, 2014; Kim & Pak, 2002). When students learn to solve well-defined problems, only their simple strategies are developed, which hinders students' reflection upon the concepts and principles, leading to inadequate conceptual development (Pulgar et al., 2021). Compared with textbook problems, context-rich problems set the context as a significant part of a problem and an essential part of its solution (Wood, 1983). It also creates a bridge linking the modeled and the authentic world. The outstanding characteristic of this kind of problem is authenticity, which is rooted in the real world. However, it is not always effective in developing students' ability to solve real-world problems characterized by complex, ill-defined, and vague methods, and so on. For instance, when well-defined problems are embedded in specific contexts, the contexts have little meaning to students. The problem-solving process that students experience is consistent with solving exercises and well-structured problems. Similarly, when extremely ill-defined problems are embedded in specific contexts, the problems are so context-dependent that the problems become no sense without the context. Thus, it prevents students from developing their problem-solving ability and meaningful transformability from school to life.

In summary, the gap based on problem types became one reason for students' difficulties in problem-solving in different contexts. Textbook problems or exercises, a typical representative of well-defined problems, provide an intermediary for training for students to solve regular problems. Nevertheless, even students who successfully solve conventional problems are often helpless facing unconventional problems. At the same time, situational problems lie between well-structured and poorly structured problems and tend to be well structured compared with real problems. It provides a medium or story background for students to connect with real-world problems

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and provides good support and promotion for students to solve problems close to the real world, yet the problem is not enough to cultivate students' ability to face the real world. The external factors that affect students' problem solving are discussed above. Next, the internal factors influencing students' problem solving and the characteristics of problem solvers will be discussed.

Problem representation in problem solving

Previous studies have found that novice students have trouble attaining expert-like skills in problem solving after traditional instruction. Substantial research has provided several reasons why experts are better problem solvers than novices (Heller & Hollabaugh, 1992; Larkin et al., 1980; Hsu et al., 2004; Wieman, 2015). One of the most important reasons is problem representations (Chi, 2018), which is the key to problem solving. Experts create more rich, more integrated mental representations than novices do (Björklund, 2013).

In the cognitive psychology domain, problem representation is generally recognized as the cognitive structure of the problem constructed by the problem solver to understand the problem and the explanation of the initial conditions and constraints of the perceived problem. In short, problem representation as an internal representation is a way of recording information in the brain. Once the problem-solvers develop a specific representation, a particular solution, always a good one, will emerge (Voss, 1988, 1991). Representation of a problem is established by building a cognitive model of a problem space.

There are three main views on the nature of the representation process. The first one is that external representation is only the stimulated output of internal consciousness. So, even if many cognitive tasks need to be completed during the interaction with the environment, all cognitive processing activities can only occur in the internal model of external representation. Therefore, when the problem-solver is faced with a task that needs to interact with the environment, he first needs to establish an internal model about the problem presentation and its environment through the coding process, and then complete the psychological operation of specific content symbols, sub symbols or other forms in this structured psychological model. Finally, through the processing procedures, the internal processing products are externalized to the environment. It is a widely accepted view in traditional AI and other fields of cognitive science (Newell, 1994). The second view emphasizes the role of external representation in problem solving. The perspective argues that the information of the problem itself and the context of the problem can be fully perceived by an individual's perceptual system, which is conducive to completing cognitive tasks. Because of the highly structured external representation itself, there is no need to establish any internal model. That is, the essence of the problem can be understood only through external representation. As Gibson (2014) said, the invariable information can be directly perceived and ensures the completion of cognitive tasks even if there is no memory, reasoning, thinking, or other psychological processes which need internal representation. In Gibson's view, the information of the environment is sufficient to determine the objectives. Therefore, the final product of perception is not an internal representation of the environment, but the constant information directly perceived from the environment. The last view is that external representation and internal representation interact to influence problem solving when one is completing cognitive tasks. Based on ecological psychology, Zhang and Norman (1994) studied distributed cognitive tasks' representational properties. They argue that external representations can be directly perceived and used without the need to be interpreted and formulated explicitly. External representation constrains the range of cognitive activities through its physical structures to anchor cognitive behavior. Moreover, even if the abstract structure of tasks is the same, tasks with or without external representation are entirely different for problem solvers.

Therefore, a consensus is found on the understanding of these three representations: (1) Problem solving involves external and internal representation, and they are independent but correlated; (2) In general, the internal representation of the problem is the key to solving the problem. Wrong or incomplete internal representation can become the most significant internal obstacle to problem solving; (3) There are two mechanisms for the external representation of problems to influence problem solving: one is to activate the internal complex cognitive process and establish the internal psychological model to form the problem space; the other one is to detect the invariable structures in the external representation directly through the perceptual system and complete the problem solving without the involvement of the activation and reasoning of some complex mental models in the internal memory system. Generally, to solve a problem it is necessary to process the information from external representations and internal representations integrated and dynamically.

Internal representations: A significant number of researchers have focused on the construction of internal

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mental problem representations. It is believed that internal representation is the beginning of problem solving by most psychologists. Internal representations play a crucial role in many aspects, such as connecting problems to domain understanding, and transferring problem solving. It is assumed to be the knowledge in memory, in multiple forms, including propositions, schemas, and neural networks. Briefly defined, it involves the problem solver extracting information from the problem context, recalling information from the memory system, and encoding information in working memory to form the psychological schema of the problem structure. The correct and appropriate internal representation is the key to solving the problem. Establishing an internal representation of problems depends on the perception of relevant problem information by the perceptual system and the explanation of perceptual information by existing experience, especially the problem examples and theoretical categories, making problems represented quickly. The situation of the problem is the essential condition for information representation. The approach, environment, and structure of problem presentation determine what information and spatiotemporal structure problem solver can be perceived. Furthermore, the knowledge, experience, and personality of the problem solver are also important factors, which are about an individual's perceptual interpretation of stimulus information and organizational construction.

External representations: External representation is an essential and intrinsic component of problem solving, and without external representation, the problem cannot be established. It is defined as the knowledge and structure in the environment and includes external rules, constraints, and relations embedded in physical layouts. The typical forms of external representation are graphs, diagrams of curves, photos, and writing symbols, often used in cognitive tasks such as problem solving, reasoning, and decision making. Many studies have shown that these forms make problem information more specific, interpretable, and processable (Chambers & Reisberg, 1985; Kleinmuntz & Schkade, 1993). External representations facilitate problem solving through symbols of an object, which represents an individual's knowledge and the knowledge structure. In this way, complex cognitive processing is promoted (Vekiri, 2002). External representation can help an individual to elaborate a problem, transform its fuzzy state into clear conditions, ease the cognitive load, and create solutions (Scaife & Rogers, 1996).

Experts and novices in representations: Distinguished with the general aspects of problem solving that psychologists focused on, educational researchers paid more attention to domain-specific problem-solving strategies. They produced a deep insight into expert-novice studies. There are many studies on physics as a classic established problem-solving discipline. What makes a distinction between experts and novices lies in the amount of domain-specific knowledge and how this knowledge is used in these situations (Ericsson et al., 2018; Foster, 2000). Experts have a large number of physics knowledge, while novices have insufficient knowledge. Experts' knowledge is highly interrelated and integrated, while novices' knowledge structure is loose and incoherent. Experts' representations are comprehensive, whereas novices represent problems in a stretched way. Furthermore, experts are good for retrieval from working memory, while novices are hard to recall unless cued by something (Horn & Blankson, 2012).

Besides differences in physics concepts, experts and novices significantly differ in their representation features. Experts use in-depth features to classify problems, whereas novices resort to superficial features in order to solve problems (Chi et al., 1981). The process of solving a problem for experts includes three steps. The first one is the description stage and transitions of the problem statement into a more domain-specific description of the problem. Secondly, one uses applicable procedures to find solutions. The last one is evaluating the solution according to criteria (Reif & Heller, 1982). Specifically, experts spend more time completing the description stage, which is regarded as a qualitative description based on principles, while novices always skip this step. Qualitative analysis is served for decision guidance of planning and evaluating (Larkin, 1979), which efficiently promotes the further solution steps. By contrast, novices lack qualitative physical explanation (Foster, 2000) and rush into directly using formulas (Larkin, 1979) or stinging together miscellaneous equations, and then their problem solving always ends at this step. The gap between experts and novices has been widely studied. It is concluded that the obstacle novices face, compared with experts, includes how to construct a problem representation generated from both internal and external sources. Primarily, external representation refers to the transition from environmental information structure, which directly or even decisively influences internal representation.

As reviewed above, external representations function as affordances that constrain cognitive activity, then training students to interact with those representations, including external and internal, should afford more significant cognitive benefits. Furthermore, if students are tuned to attend to the external properties of the problem, they will be able to acquire the understanding of the problem successfully, which is crucial to solving the problem and moving on to the next step. However, it depends on problem space, which provides opportunities for students to develop their problem-solving abilities. Researchers pay attention to theoretical descriptions of problem solving

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primarily based on solving *textbook problems*, which are simplified and idealized situations with narrow problem space for students to construct; generally, only the internal representation space is included. In many physics' textbooks, external representations are usually expressed in direct mathematical forms, which makes students difficult to understand the underlying physical nature concepts (Huffman, 1997). For *real-life problems*, it is ill-defined, open-ended, and has multiple possibilities, so students may suffer from a so high cognitive load that they quickly fail to solve. The problem-solving ability transformation between school and life is hard to eliminate for school education. For *context-rich problems*, real scenarios and embedded mathematical forms reduce unnecessary cognitive load and motivate students to solve problems. The context-rich problems provide textbook problems with a real-world background to bridge the problem-solving gap between the real world and school education. They are essentially based on the textbook problems, with the situation as the link to the real world, to train students' problem construction ability. From textbook problems to real-world problems, from well-defined problems to ill-defined problems, context-rich problems are closer to the textbook problems, compared with the more obvious difference from real-world problems, and their problem space is also limited. It is important to note that expanding problem space to represent both the external representation and the problem solver's internal representation broads the range of distributed cognitive tasks. Moreover, external representation promotes the generation of a psychological model, which is a crucial feature in the learning process. However, students' understanding can only be developed when external representation is consistent with its cognitive internal representation.

Research Aim and Research Questions

Based on the literature review, this study hypothesizes that the different essence of cognitive processes included in different kinds of problems results in obstacles to the problem-solving ability transfer for students in school and real life. For example, there have been several types of problems in physics education, such as exercises, context-rich problems, and real problems, which are significantly different in the continuum of well-structured ill-structured problems. Here, it is supposed that expanding the problem space, including sufficient external and internal representation spaces, can benefit from improving students' problem-solving ability, especially the gap between problem-solving ability in the real world and school education can be further bridged.

Therefore, this study aimed to:

1. Based on the theoretical framework of ecological problem representation, propose a new problem type, different from the existing problem types, which is named *primitive physics problem*.
2. Describe the characteristics of primitive physics problems theoretically and empirically. As for the theoretical description, the critical attributes of the new problem type will be examined, which is different from the existing problem types and explain the significance of training students' problem-solving ability.
3. Design an instrument based on primitive physics problems for upper-secondary school students.

Theoretical Framework

Based on the synergetic theory and ecological problem representation, this study proposes the self-organizing representation theory (SORT) by combining Newell's and Simon's (1972) Theory of Human Problem Solving and Representations in distributed cognitive task developed by Zhang & Norman (1994).

In the theoretical framework, problem solving is assumed to combine continuity with mutation, independence with correlation, control with spontaneity, cooperation with competition, and necessity with contingency. Representation-state is the state of problem representation, which is the relatively stable level of problem representation at a specific time in problem solving. Representation-state is the state in which the internal knowledge of the problem solver interacts with the external information in the process of problem solving. There are two cognitive models: data-driven and concept-driven. When the problem is presented to the solvers, the initial state of existence is the separation of external information and internal information, which is a non-representation state; Finally, when the problem is solved, it is the interaction of internal and external information that realizes the complete representation of the problem.

Based on SORT, it is assumed that there is a process in which the representation state changes when solving physics problems. The whole process includes six different representation states add: abstraction representation, assignment representation, image representation, physics representation, methodology representation, and mathematics representation.

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Abstraction Representation. Students can create mental entities for a higher level of organization of new concepts by the process of abstraction (Ainsworth, 2006). What information needs to be discarded and retained from the physics problem requires the students to make their own decisions. The process of abstracting ideal objects from the real physical phenomenon is to simplify and purify the process of object movement and to sublimate it into an ideal state by imaginative, intuitive, and logical thinking so that the essence of the problem can be reflected more clearly.

Assignment Representation. Assignment representation is a unique representation type, rarely involved in the routine problem-solving process. Students should set physics quantities according to their needs and list the known and unknown quantities. Intermediate quantities are also necessary at times to be set up, which appear in the process of solving the problem, but they do not appear in the final equation. Indeed, the physics quantities set in this stage are not required to be consistent because there is no need for uniform and fixed assignments to solve problems.

Image Representation. Image representation is to sketch in the problem-solving process, which is included in traditional exercises and physics problem-solving processes and needs students to complete independently with the help of image thinking.

Physics Representation. A major aspect for students to solve physics problems is considering what primary principles or concepts can be applied to problem solving (Yerushalmi et al., 2007). The process of identifying and using physical conceptions and principles to solve problems refers to physics representation, which means students need to relate the physics problem to the physical concepts and principles they have learned before.

Methodology Representation. In this stage, scientific methodology or specific methods should be identified by students to solve problems, which reflects the relationship between physics knowledge and physics methods.

Mathematics Representation. It refers to a series of mathematical deduction steps, including column equation, solution equation, necessary mathematical transformation, and approximation, which is more abstract than physics representation (McDermott & Larkin, 1978).

The changing pattern of the representation state differs for different solvers, and it shows some continuity and discontinuity, linear and nonlinear, static, and dynamic. The characteristics of the transition of states are below.

Linear and Nonlinear. The change of these problem representations usually is nonlinear. However, in a specific stage, the factors that affect the problem representation have relatively stable or linear change characteristics, so the representation state also has a local linear change process. The linear and nonlinear changes of the representation state determine that the process of problem solving has the characteristics of linear and nonlinear changes.

Static and Dynamic. When solving this kind of problem, solvers are always in a cognitive field, which is influenced by many factors and shows the static and dynamic combination characteristics. When there are many interactions between internal and external factors, the representation of the problem needs to be repeated or even reconstructed, and the representation state is dynamic. When the interaction between internal and external factors is less, the representation state is more static.

Assimilation and Adaptation. Assimilation means that the subject extracts and identifies the external given problem condition information and understands the meaning and mutual relationship of the information; On the other hand, based on information assimilation, adaptation forms some abstract and general problem representations. There are two critical factors affecting information assimilation, and one is the extraction of external information, the other is the activation of internal related knowledge.

Research Methodology

General Background

To develop a measuring instrument of primitive physics problems for upper-secondary school students, this study was divided into two parts. For Part I, based on an extended theoretical framework, qualitative research was carried out to propose a new type of problem, which was described qualitatively and quantitatively. Next, for part II, a measuring instrument consisting of a series of primitive physics problems was developed. To test the reliability and validity of the instrument, data of students' responses to the instrument was collected. The test was applied at the beginning of the 2019 – 2020 school year. The test time was approximately 45 minutes.

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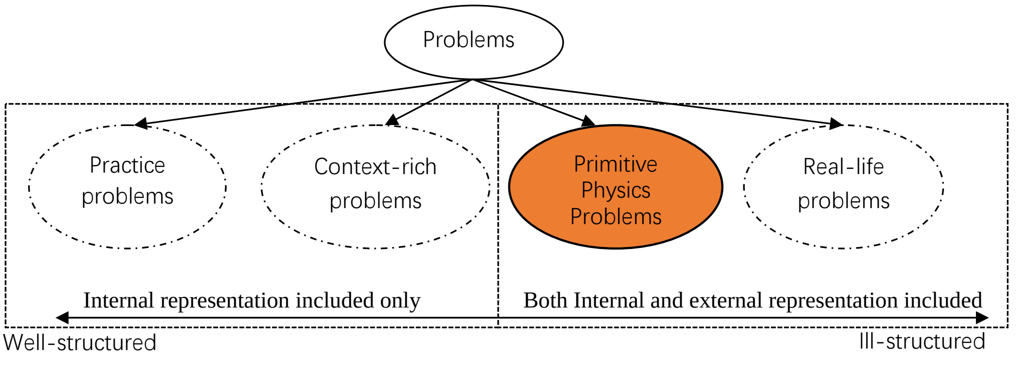
Part I: A new type of problem: Primitive Physics Problem

Primitive Physics Problem

A primitive Physics Problem describes a problem abstracted from the objective physics phenomena in real life. Thus, the Primitive Physics Problem is situated between context-rich and real-life problems, far away from a textbook problem and close to a real-life problem along the continuum from well-structured to ill-structured. For instance, the graph in Figure 1 shows four categories of problems.

Figure 1
Typology of Problems in Physics



The *primitive physics problem* refers to the typical phenomenon that has not been abstracted in nature, social life, and production. It has the following characteristics:

1. It is a description of the phenomenon, without abstracting the phenomenon to any extent;
2. It is a text description, usually without any known conditions, and the implicit variables and constants need to be set by students;
3. There is no schematic diagram, and students need to draw the images needed to solve the problems themselves;
4. It is not conventional for students and cannot be solved by simple imitation;
5. From real-life situations;
6. It is exciting and charming and can arouse students' thinking and put forward intellectual challenges to them;
7. There is not necessarily a unique answer. Students of different levels can answer from the simple to the deep;
8. Solving it needs to be accompanied by individual or group activities.

An example for a typical primitive physics problem is as follows: Some people think it is not safe for an adult to hold a baby in a car. Now, please estimate how much force it takes to hold a baby in a very short crash. There are great differences between the *primitive physics problem* and Exercise. Exercise is a problem that abstracts, simplifies, and decomposes the phenomenon. It is a manual exercise. It has the following characteristics:

1. It is not a description of the phenomenon, but a high degree of abstraction of the phenomenon;
2. Although it is also a text description, all the known conditions have been given, so students do not need to set them by themselves;
3. All the images needed to solve the problem have been drawn, and students are not required to draw them by themselves;
4. It is routine for students, which can be solved by simple imitation;
5. A few of them come from real-life situations, while most of them do not;
6. Lack of interest and charm mainly used to train students to master knowledge;
7. There is only one answer;
8. Individual solution, no need for group activities.

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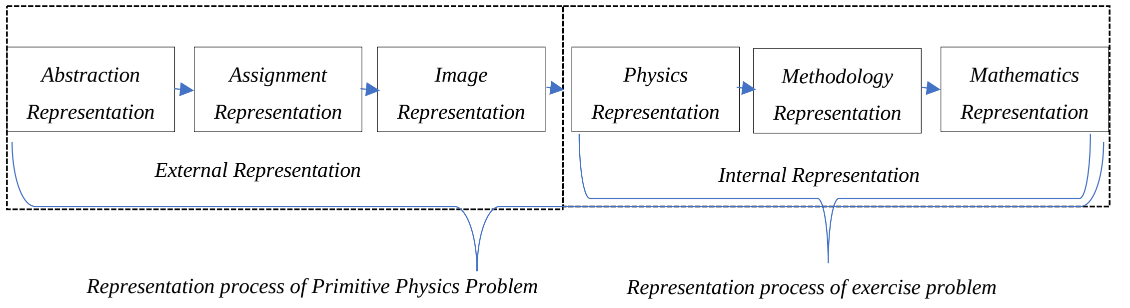
An example for a typical exercise problem is as follows: A typical exercise problem: It is not safe for an adult to hold a baby in a car. Please calculate: in a 0.1 s crash, if the vehicle speed is 60 km / h before the crash, how much force does one need to hold a 10 kg baby.

From the perspective of problem space, both the *primitive physics problems* and exercises include three internal representations: physical representation, method representation, and mathematical representation. In addition, the essential distinction from exercises is that the *primitive physics problems* include not only three internal representations but also external representations including abstract representation, assignment representation, and image representation. As for abstraction representation, it refers to grasping the main factors, ignoring the secondary factors, extracting the element and structure with physical domain characteristics from the description of the problem to facilitate the transformation of the prototype into a preliminary physical model. As for assignment representation, it needs to set multiple physical quantities, like constants, variables, and intermediate variables, which makes the model numerical. In contrast, exercises or textbook problems with the characters of sufficient information, static state, and no interaction with the real world, do not have these problem spaces.

Although the exercises are related to phenomena in form, they provide detailed data. However, they do not provide students with real-world problem situations. Therefore, the cultivation of students' ability to analyze and solve problems is severely reduced. The original problem is to embed each to be known quantity in the natural phenomenon instead of giving it directly. Based on the analysis of the situation, students need to obtain the required variables and data through assumptions, abstractions, and means and then construct an ideal model. After a layer of "stripping" process, the conclusion "breaks the cocoon." The relationship between primitive physics problems and exercises is shown in Figure 2.

Figure 2
Representational Relationship between Traditional Exercise and the Primitive Physics Problems



The difference between primitive physics problems and context-rich problems is also obvious. For context-rich problems, what connects with the real world is the background of the problem. The space embedded in the problem is a "story" related to the real world. Students need to construct their problem representation process in the context of materials representing the real world. For the *Primitive Physics Problems*, what connects with the natural world is the problem itself. That is, the problem itself is a description abstracted from the physical phenomena in the real world. Students need to abstract and assign values to the problem description through an external representation process to transit to the solvable domain of routine problem solving.

Part II: The development of the instrument of Primitive Physics Problem

Participants

In this study, 1000 students were randomly selected from 10 upper-secondary schools in China. The research involved 811 valid samples, including 417 boys and 394 girls after eliminating invalid information samples. The characteristics of the screened samples maintained a high degree of consistency with the original overall sample distribution characteristics. All of the participants had completed the entire physics course, including junior high school and upper-secondary school, and had an excellent academic background. This academic excellence was measured based on the Lawson classroom test of scientific reasoning (LCTSR).

Given that the participants came from different schools, they were invited to enroll in the test representatively.

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Therefore, the test was administered with the same length of time and other test conditions. All participants volunteered to participate in this study. All parties, including students, teachers, and parents signed a formal consent form for their participation in the study, which described the activities in which they would be involved, and ensured that all personal data would be treated anonymously and confidentially.

Instrument and Procedures

Based on an extended theoretical framework and the new type of problem proposed in this study, six primitive physics problems were designed. Next, the six problems were reviewed by three science education experts who worked in the Faculty of Education at Capital Normal University for the readability, scientificity, and rationality of these problems and how well they were likely to measure students' thinking process. Two items were excluded for their lack of appropriateness, leaving 4-items. The instrument appropriate for upper secondary school students used to test included four primitive physics problems based on the classic physical phenomena in real life.

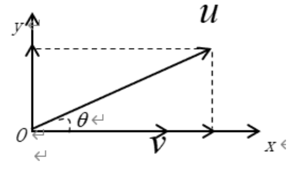
Moreover, according to the six representations included in the problem, the rubric of the instrument was developed. The example of the rating criteria was listed in Table 1. The score for each representation was a dichotomy scoring system, which scored 1 or 0. "1" was assigned if the representation did occur, and "0" if it never occurred. Take assignment representation as an example, students could get 1 point in the grading process if they ultimately set sufficient physical quantities and 0 points if any setting was incomplete or incorrect. Each problem was resolved with six representations, so the total score for each question was six points, and the whole final score was twenty-four. One of the measuring instruments of upper secondary school students' primitive physics problem was as following example. (See Appendix A for complete instrument and Grading Rubric)

Example: The Primitive Physics Problem 1—Ship Roll Reduction

Problem: On December 24, 1990, the Chinese scientific research vessel polar encountered a strong wind at sea and was impacted by periodic waves. As we all know, if the frequency of wave impact force is close to the natural frequency of ship swing, the ship swing will be intensified. Once the resonance state is reached, the ship may capsize. At this time, the polar adopted the measures of changing course and reducing speed, which reduced the swing range of the ship.

Please explain with an expression why polar could reduce the ship's swing amplitude by changing the course and reducing the speed.

Table 1
Rating Criteria of the Primitive Physics Problem for the ***Ship Roll Reduction***

Representations	Rating Standard
Abstraction Representation	Ignore the ship's length, height, width, and mass, and regard the ship as a particle
Assignment representation	1. Set the speed of the ship to be u; 2. Set the speed of the wave to be v; 3. Set the velocity of the wave relative to the ship to be v'; 4. Set the length of the wave to be λ; 5. Set the length of the wave relative to the ship to be λ'; 6. Set the frequency of the wave to be f; 7. Set the frequency of the wave relative to the moving ship to be f'; 8. Set the angle between the speed direction of the ship and the wave propagation direction to be θ.
Image Representation	1. Draw rectangular coordinate system xoy; 2. Draw the velocity of the wave v, along 3. the x -axis; 4. Draw the speec f the ship u, in the 5. the direction of θ angle to the x -axis; 6. Draw the angle θ between the ship's speed and the wave's speed. 

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Representations	Rating Standard
Methodology Representation	1. Velocity decomposition method (including establishing the coordinate system and specifying positive direction); 2. Induction (from special to general).
Physics Representation	1. The formula among wavelength, frequency, and wave velocity $f=\frac{v}{\lambda}$.
Mathematics Representation	1. Firstly, the situation that the ship's velocity direction is the same as the wave propagation direction is studied. The speed of the wave relative to the ship: $v'=v-u$; The length of the wave is constant for a moving ship: $\lambda'=\lambda$; So that the frequency of wave impact force ship received: $f'=\frac{v'}{\lambda'}=\frac{v-u}{\lambda}=f-\frac{u}{\lambda}$. 2. Then, the situation that the ship's velocity direction is perpendicular to the wave propagation direction is studied. The speed of the wave relative to the ship: $v'=v$; The velocity of a wave is the velocity of its propagation. When observed perpendicular to its propagation direction, the observer's motion does not affect the result: $\lambda'=\lambda$; So that the ship received the wave's impact force frequency is: $f'=\frac{v'}{\lambda'}=\frac{v}{\lambda}=f$ 3. The results of inductive situations 1. and 2.

Data Collection

A printed version of the measuring instrument was answered by students participating in the study. The test was applied at the beginning of the 2019-2020 school year. The collection of these data was conducted during physics classes. The test was administered with the same length of time and other test conditions. The teacher of each class was responsible for the test implementation.

Data Analysis

The difficulty level of the test (P), is an important indicator to measure the quality of the test, which together with discrimination affects and determines the quality of the test. The difficulty level of the measuring instrument was calculated using a passing rate, with a minimum value of 0 and a maximum value of 1. A small difficulty value indicates that the test is difficult, while a large value indicates that the test is easy.

Discrimination (D), an index of discrimination, is an indicator of the ability level of the participants. The discrimination of the measuring instrument was calculated using the difficulty level of the top 27% of the whole score group (P_H) and that of the bottom 27% of the whole score group (P_L). Then its calculation formula is $D=P_H-P_L$.

Discrimination is generally between 0 and 1, and 0.4 or higher indicates that the question is well discriminated.

To assess the reliability of the instrument, Cronbach's alpha coefficient of internal consistency, the item-total correlation by split-half reliability, and t-tests were used. SPSS 22.0 software was used for statistical analyses.

To test the construct validity of the instrument, confirmatory factor analysis (CFA) was used. Several indicators are used to test the compatibility of a proposed model with data. χ^2 goodness-of-fit statistics determines the size of the discrepancy between the sample and fitted covariance matrices. Because the size of the data set affects the value for p, the supplement fit indexes need to be used. In this study, Tucker-Levis Index (TLI), Comparative Fit Index (CFI), Standardized Root Mean Square Residual (SRMR), and Root Mean Square Error of Approximation (RMSEA) indexes were used. CFI and TLI values over 0.95 indicate perfect fit with the model, whereas values between 0.85 and 0.90 indicate acceptable fit (Marsh et al., 2004). For RMSEA and SRMR, values 0.20 and below indicate acceptable fit. SPSS 22.0 software was used for statistical analyses. MPLUS 8.0 software was used for statistical analyses.

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Research Results

Difficulty Level and Discrimination Analysis

The difficulty level of the measuring instrument was calculated as $P = 0.220$. The result demonstrates that the instrument of 12th grade primitive physics problem is slightly difficult. The discrimination of the measuring instrument was calculated, $D = 0.406$, which indicates that the measuring instrument of the primitive physics problem can distinguish students with different abilities.

Reliability and Validity Analysis

The reliability is computed. The coefficient of Cronbach's Alpha value is 0.742. Nunnally recommended that alpha values be at least 0.7 (Nunnally, 1978), suggesting a higher degree of consistency among the problems.

Further Confirmatory Factor Analysis (CFA) was used to testify the construct validity. Using MPLUS to construct the first-order model, the fitting index of the model is shown in Table 2. Models (e.g., CFA) could be accepted if they met the following requirements: (1) the ratio of c^2 and d*f* was statistically nonsignificant (p>.01); (2) Standardized Root-Mean-Square Residual (SRMR) and Root-Mean-Square Error of approximation (RMSEM) were smaller than 0.08; and (3) Confirmatory Fit Index (CFI) and gamma hat were more significant than 0.90 (Marsh et al., 2004). The values of CFI (0.931) and TLI (0.884) are more significant than 0.80 while that of SRMR (0.034) and RMSEA (0.191) (see Table 2), which fit the evaluation index. Thus, the result of confirmatory factor analysis implies the fitting index of the model is acceptable.

Table 2
Model Fitting Index of the Primitive Physics Problem Instrument

χ^2	df	TLI	CFI	AIC	BIC	SRMR	RMSEA
275.37*	9	0.884	0.931	8655.25	8739.75	0.034	0.191

Based on the data analysis, it can be seen that the primitive physics problem instrument has moderate difficulty and good discrimination, and the problems are closely related to the real situation. Moreover, the instrument also has high reliability and validity, which made it possible to identify students' ability to solve physics problems effectively.

Discussion

Representation Style of Primitive Physics Problems: from Internal Representation to External Representation

High hopes are placed on that problem solving can be taught as a technique like computing. Traditional school training often emphasizes the construction of internal representation through practice, which leads students to memorize formulas to find algorithm solutions without a deep understanding of concepts. According to the mental mode theory, problem solving depends on the construction and operation of internal representation. The construction of the psychological model is formed by the connection between the problem description elements and the underlying knowledge base. Exercises contain elements to promote the construction of the psychological model, which is the internal representation mentioned in this study.

Further, students have difficulty with solving real-world problems in the context of traditional school training. Research in physics education also found that more emphasis on qualitative representation was helpful to improve the achievement of student problem solving. So, it is critical for students to learn how to understand a problem before solving it, which refers to interacting with appropriate representations.

The Primitive Physics Problems supply students with sufficient problem space, including external representations and internal representations, and the nature of problems they face are changed completely. When students face primitive physics problems, they need to extract the information with physical characteristics from the problem description, which involves transforming the problem prototype into the preliminary physical model. The representation process distinguishes the primitive physics problems from other types of problems: exercises, context-rich

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problems, and real problems in the continuum from well-structured to ill-structured problems. Specifically, solving exercises and context-rich problems does not include this process, and to solve real problems is challenging for students to carry out this process efficiently. In addition, according to the preliminary physical model, to set the physical quantities and parameters, to draw images actively, refer to experiencing assignment representation and image representation, which is the transition way from prototype to internal representation structure. These three representations together constitute the external representation space of primitive physics problems, which is also the particular space of this problem. When students succeed in the transformation of the problem statement from it to wanted state, in many different formats, like verbal, visual, mathematical representations, it is said that students have mastered the skills of how to transform real-world problems into patterns which are consistent with their internal psychological structure and finally solve them.

Cognitive Driven Mode of Primitive Physics Problem: from Data-Driven to Concept-Driven

There are two ways of problem-solving cognitive driven mode: one is data-driven, that is, scientists firstly collect a large amount of data, then analyze these materials to find out the patterns, and then explain these findings; the other is concept-driven, that is, scientists first put forward hypothetical theories, then make predictions, and last verify theories supported by facts.

Experts are distinguished from novices because of their cognitive mode for problem solving. When solving a new problem, novices are more likely to lack knowledge structure and likely jump into quantitative expressions quickly, including haphazard formula-seeking and solution pattern matching. So, they showed a data-driven model, which is a process from bottom to up. It takes observation and the discovery of scientific facts as the starting point of scientific research. Its processing takes scientific research data as the processing object and makes the processing information meet the requirements of the explanation of a phenomenon. In contrast, experts show more concept-driven patterns in solving problems. They tend to redescribe the problem quickly and analyze a problem qualitatively based on principles and concepts at first, and then elaborate on them in greater mathematical detail. The experts tend to work forward from given values and known quantities to the wanted quantity. It is said that they showed a concept-driven mode, which refers to the top-down procedure. It takes the contradiction between scientific theory and empirical facts and the contradiction of scientific theory itself as the starting point of scientific research. Information satisfies the consistency of the theory itself.

In physics education, it is necessary to support students to become an expert equipped with problem-solving skills. Students have been exposed to long-time textbooks problems or exercises. Textbook problems or exercises are depicted in mathematical forms and full of data, resulting in difficulty in perceiving and grasping the underlying concepts or explanatory principles highlighted by the theory under consideration. The guidance leads students to focus on the surface features of problems and train superficial cognitive processing, which shows a data-driven mode. Exercises tend to encourage means-end rather than knowledge development strategies because students frequently focus on finding the equation that best fits the problem. Exercises encourage students to use a data-driven cognitive mode. The "data" or "condition" of exercises is the fundamental defect of exercises. "Data" is not only the crutch of students' thinking but also a critical "hint." If students are only allowed to practice physics exercises without solving physics problems, it would be difficult for students to lose this "crutch" forever, affect their ability development, and cause obstacles for students to develop to the expert.

The Primitive Physics Problems describe physical phenomena and keep the "original flavor" of phenomena. Compared with exercises, the Primitive Physics Problems only describe phenomena, which do not contain any data or an abstract model. Because it hides the "data" or "condition" in the real phenomenon, it needs students to determine "data" or "condition" by themselves according to the phenomenon through assumptions, abstractions, and other methods. Therefore, the solution of the Primitive Physics Problem must be concept-driven processing instead of data-driven processing. Compared with concept-driven, data-driven often needs the "starting point" or "fulcrum" of processing. When solving the Primitive Physics Problem, it has unknown conditions, to force students to give up data-driven processing. In other words, when students learn how to solve Primitive Physics Problems, the concept-driven cognitive mode is used, including description, problem analysis qualitatively based on concepts, which are in line with the experts' mode for solving problems.

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Cognitive State of Primitive Physics Problem: from Organized to Self-Organized

The cognitive state refers to the organizational state of the problem solver's brain or the "phase" of the problem solver's brain. According to German theoretical physicist Hermann Haken, the evolutionary form of organization can be divided into two categories: be-organized and self-organized. If external instructions organize a system, it is be-organized; If there is no external instruction, the system automatically forms an orderly structure according to some tacit rules, it is self-organized. From the perspective of system theory, "self-organized" refers to the process that a system develops from simple to complex, from rough to detailed, and constantly improves its complexity and fineness driven by internal mechanisms (Sherblom & Stephen, 2017).

This study believes problem solving involves the transition from certainty to diversity and uncertainty, from linear to nonlinear, from knowledge poor to knowledge rich. The solution of primitive physics problems is a self-organization process of problem solvers to represent the state of problems, and this process has the characteristics of nonlinearity, mutation, and self-organization. In other words, solving primitive physics problems combines continuity with mutation, independence with correlation, cooperation with competition, control with spontaneity, and a necessity with contingency. As Anderson's ACT-theory (Adaptive Control of Thought) said the process of complex cognitive skills was divided into three stages. Firstly, learners generate initial solutions by weak methods in new problem situations. Secondly, a knowledge compilation process facilitates the movement from slow, controlled processing to more automated processing. Thirdly, whenever cognitive rules are successfully applied, cognitive rules will accumulate strength. Finally, after extensive practice, this reinforcement process may eventually automate the performance of problem-solving skills.

Physics exercises usually state the events that follow one or some disciplinary principles indirectly. The cognitive process of physics exercises is based on specific cognitive strategies and skills to complete the disconnection between knowledge and cognitive chain "caused by" indirectness, to make the problem elements of physics exercises explicit. The event with dominant characteristics can clearly show the "context" of the event. When solving this kind of problem, the process is intervened by the outside factors and has the typical characteristics of weak self-selection and dynamic evolution, weak initiative innovation, and adaptability. Limited by the restricted problem space, students can only carry out "cloze" problem solving, showing the characteristics of the cognitive state of being organized.

For a long time, there has been a phenomenon of "the sea of exams tactics" in Chinese physics education, which has not been significantly improved so far. Up to now, there is a new trend word, "Equation solver from a small town," to describe students skilled at exams rather than solving problems. Most of the cognitive state of Chinese students is in the state of being organized, and only a few of them are in the state of self-organization. The primitive physics problem makes students return to the phenomenon and pay attention to the "real world." The return is consistent with the process of students' knowledge generation and mastery, which needs interaction in the real and natural social environment. Through a certain amount of primitive physics problem training, when students solve practical physics problems, a variety of problem-solving strategies can be quickly retrieved without having to rummage to compare the types of questions they have done so that they can preview the next step in their brain when dealing with the previous step. Even when students are carrying out creative activities, they can also rely on physical intuition rather than experience to explore the right way to solve the problem. In this sense, primitive physics problem training can not only make students learn physics knowledge but also promote the development of students' physics cognitive state. At the same time, it is precisely because the primitive physics problems apply the strict control of exercises to physical phenomena, and can become exercises after being abstracted, which has the function of efficiently completing the internalization of indirect empirical knowledge to a certain extent, and better unifies the internal validity and external validity of physics education, Thus, it provides beneficial enlightenment for breaking the phenomenon of "sea topic tactics" in physics education.

Conclusions and Implications

In this study, a new type of problem was added to the existing problem categories based on the problem continuum. It provided a bridge between the problem-solving training in school education and the problem-solving practice in real life. It provided more effective tools and teaching scaffolding for students to develop real-world problem-solving abilities. Further, the primitive physics problem instrument was developed, and the instrument also has high reliability and validity, which made it possible to identify upper-secondary students' ability to solve physics problems effectively.

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There are two limitations to this study. First, only one type of task was used with the participants to examine the effects of the overall response. As such, it is possible that the response collected may be confined to these four items. Additionally, more data could be collected by adding more items. Alternatively, students could have been provided with the answer sample as a scaffold to solve the test's problem. These options are left for future research. The second limitation of this study is that the students with high-level performance were sampled, which leads to a certain limitation in the application of instruments. Furthermore, a more general sample should be chosen to carry out the study. Finally, it is worth noting that the focus of this study is to propose a new type of problem and preliminary exploration of measuring instruments.

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Declaration of Interest

Authors declare no competing interest.

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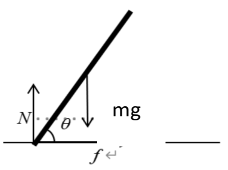
Appendix: The Primitive Physics Problem and Grading Rubric

The Primitive Physics Problem 1—Bicycle turning

Problem: When a cyclist turns, he is always leaning at a certain angle. What is the angle value so that he turns without overturning?
Please explain with expression to support your answer.

Table 3.
Rating Criteria of the Primitive Physics Problem 1 ***Bicycle turning***

Representations	Rating Standard
Abstraction Representation	1. Abstract bicycle and human as straight bar model.
Assignment representation	1. Set the supporting force of the ground to be N;
	2. Set the friction force to be f;
	3. Set the mass of the bar to be m;
	4. Set the velocity of the bar to be v;
	5. Set the length of the bar to be L;
	6. Set the turning radius to be R;
	7. Set the angle between the straight bar and the ground to be θ.
Image Representation	1. Draw the mass center of the straight bar be located at the middle point of the straight bar G.
	2. Draw the angle θ between the straight bar and the ground;
	3. Draw the directions of supporting force, gravity, and friction force. 
Methodology Representation	1. Model method (building a straight pole with people and bicycles);
	2. Supposition method (supposing that the straight bar rotates around the mass center of the straight bar).
Physics Representation	1. Balance between two generalized forces;
	2. The formula of centripetal force;
	3. The moment balance principle.
Mathematics Representation	1. Supporting force and gravity balance in the vertical direction: $N = mg$;
	2. In the horizontal direction, friction acts as a centripetal force: $f = \frac{mv^2}{R}$;
	3. The moment sum of friction force and supporting force to the center of mass is zero: $NL\cos\theta = fL\sin\theta$;
	4. $\cos\theta = \frac{f}{N} = \frac{mv^2}{R}/mg = \frac{v^2}{Rg}$, so, $\theta = arc\cot\frac{v^2}{Rg}$.

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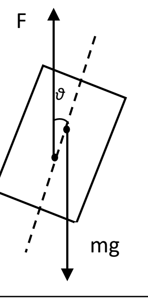
The Primitive Physics Problem 2—"Vasa" capsizing

Problem: On August 10, 1682, in Stockholm, Sweden, the largest warship, Vasa, was making its maiden voyage. When a breeze came, it capsized and sank! It's been a mystery for hundreds of years. On April 24, 1961, the ancient warship, which had been sleeping for hundreds of years, was finally salvaged, and the mystery of the wreck was revealed.

Please use your physical knowledge to quantitatively explain the mystery of the "vasa" capsizing.

Table 4
Rating Criteria of the Primitive Physics Problem 2 ***"Vasa" capsizing***

Representations	Rating Standard
Abstraction Representation	1. Ignore wind-force; 2. Abstract Vasa ship as a rigid body with a certain mass.
Assignment representation	1. Set the gravity of a ship to be mg; 2. Set the buoyancy of a ship to be F; 3. Set the inclination of the ship to be θ; 4. Set the intersection of the ship's axis of symmetry and the water surface to be O; 5. Set the center of buoyancy at point f located on the ship's symmetry axis and set the distance from the point O to be l; 6. Set the center of gravity at point G located on the ship's symmetry axis and set the distance from the point O to be L.
Image Representation	1. Draw the gravity of a ship; 2. Draw the buoyancy of a ship; 3. Draw the inclination of the ship; 4. Draw the axis of a ship. 5. Draw the ship balance situation: center of gravity is higher than the center of buoyancy 
Methodology Representation	1. Model method (building vasa into a rectangular object with symmetrical shape); 2. Hypothetical method (assuming that the vasa rotates around the intersection of the axis of symmetry and the water surface).
Physics Representation	1. Principle of two forces balance; 2. Principle of moment balance.
Mathematics Representation	1. The gravity and buoyancy of a ship are equal when a ship floats on the water: $mg = F$; 2. The moment of gravity ship received: $mgL \sin\theta$; 3. The moment of buoyancy ship received: $Fl \sin\theta$; 4. The resultant moment ship received: $Fl \sin\theta - mgL \sin\theta = mg(l-L) \sin\theta$. 5. $l > L, mg(l-L) \sin\theta > 0$, the center of buoyancy of the vasa was above the center of gravity, the moment on the vasa does not provide the restoring moment, so the vasa capsized.

The Primitive Physics Problem 3—Basketball landing

Problem: A basketball falls freely from a certain height, bumps into the ground, then bounces, rises to a certain height, and then falls freely, then bounces, falls again and again until the basketball is still.

Please deduce the expression of basketball acceleration changing with time for the whole process, and draw the image of basketball acceleration changing with time.

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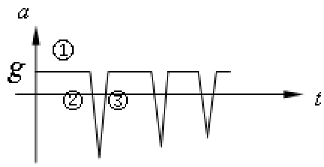
Table 5.
Rating Criteria of the Primitive Physics Problem 3 ***Basketball landing***

Representations	Rating Standard
Abstraction Representation	1. Ignore air resistance; 2. Abstract basketball as an elastic body with a certain mass
Assignment representation	1. Set the quality of basketball to be m; 2. Set the spring force of basketball during touchdown to be f; 3. Set the equivalent elastic stiffness coefficient of basketball to be k; 4. Set the shape variable of basketball to be x; 5. Set the acceleration of basketball to be a; 6. Set the time to be t. 
Image Representation	1. Draw a straight line parallel to the t -axis, the acceleration of basketball in the air remains constant; 2. Draw the change of acceleration in the process of deformation and compression of basketball; 3. Draw the change of acceleration in the process of recovery; 4. Draw the peak of the line gradually moves up but does not exceed the horizontal axis.
Methodology Representation	1. Hypothesis method(assuming that the elastic force changes linearly with time); 2. Model method (building a basketball into a spring model).
Physics Representation	1. Hooke's law; 2. Newton's second law.
Mathematics Representation	1. Basketball in the air only gravity, constant acceleration: g. 2. In the process of contact with the ground, the elasticity of basketball: $f = k_1 x$; 3. Then assuming that the basketball shape variable changes linearly with time, then in the compression phase: $x = k_2 t$, $f = k_1 k_2 t = kt$; In the recovery phase $x = k_2 \ (-t)$, $f = k_1(-k_2 t) = k \ (-t)$; 4. In the compression phase, the elasticity of basketball: □□, according to Newton's second law: $mg - kt = ma$; so $a = g - \frac{kt}{m}$; 5. In the recovery phase, the elasticity of basketball: $mg - k(-t)$, according to Newton's second law: $mg - k(-t) = ma$, so $a = g + \frac{kt}{m}$.

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