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# A study of conceptions of preservice physics teachers in relation to the simple pendulum

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**Abstract**
There is a huge body of research supporting a positive correlation between teachers' content knowledge and better pedagogical practice. In this context, this study revealed serious gaps in a cohort of preservice physics teachers' understanding of the simple pendulum. It also pointed to their poor grasp of some fundamental concepts in physics. Understanding the simple pendulum thoroughly requires the application of elementary kinetics of circular motion. This makes the scientifically accurate analysis of the simple pendulum motion reasonably complex, thereby offering potentially fruitful opportunities to probe the teachers' understanding. A questionnaire based on the simple pendulum and subsequent interviews were the research instruments. The findings demonstrate the gaps in the teachers' content knowledge, which could be addressed via initial teacher education and continuing professional development programmes for the teachers.

## Introduction

This study is motivated by the role played by the teachers' subject content knowledge in the pedagogy (Schwab 1978, Shulman 1986, 1987). The content knowledge is the knowledge of 'the facts and concepts of science' (Kind 2012, p. 59). Studies indicate the existence of a positive correlation between the teachers' classroom performance and their content knowledge (e.g. Dobey and Schafer (1984), Sanders *et al* (1993) and Gess-Newsome and Lederman (1995)). Furthermore, the research has indicated that 'teachers with low content knowledge tend to rely heavily on textbooks, talk a lot, ask few questions, and avoid cognitively challenging activities' (van Driel *et al* 2014, p. 852). This kind of impact on the teachers' classroom teaching very likely has an adverse effect on the students' engagement. In short, any gaps in the content knowledge restricts the development of the broader teacher knowledge base that is essential for a better teaching practice (Berry 2012).

There is evidence indicating that preservice and in-service teachers both exhibit difficulties in their knowledge about force, and other connected ideas such as acceleration and velocity (Kruger *et al* 1992, Yip *et al* 1998, Trumper 1999, Kikas 2004, Mashood and Singh 2012a, 2012b). However, very few studies of inservice or preservice physics teachers appear to have involved the simple pendulum, in spite of its wide use as a model in demonstrations and a starting point for learning more complex ideas in physics, for instance, simple harmonic motion. Furthermore, the same appears true for the topics of circular motion and rotational motion. Thus, it can be concluded that the simple pendulum remains an underexplored focus of research in the physics teachers' conceptual understanding.

## The simple pendulum

The pendulum is fairly basic in its physical structure as well as in terms of the forces involved. Furthermore, the simple pendulum is a part of the A-level physics curriculum in the UK which implies that it is necessary for the teachers to understand it well.

The bob of the simple pendulum performs circular motion involving both the tangential and radial acceleration. Due to this, the pendulum can play a significant role in developing a sound understanding of acceleration of a general planar motion that goes beyond the 1D conception of acceleration which is associated with the changes in speed alone. A teacher with good grounding in the kinematics of circular motion could help the students understand that, most generally, mere tangential acceleration cannot bring about a change in direction and mere radial/centripetal acceleration cannot cause a change in speed.

Investigating preservice teachers' command of this topic would give an insight into how they think. This could act as a valuable input for designing teacher education programmes. In order for the research outcomes to be of value as the input to these programmes, the aim was not only to find what, if any, the prevalent inadequacies in their understanding might be, but also the nature/causes of those inadequacies. Thus, the study focused on the preservice physics teachers' understanding of the simple pendulum.

## Research question and methodology

The study had two research questions—(i) What is the reliability of the questionnaire used as a tool for assessing the knowledge of circular motion by way of treating the simple pendulum as an example of circular motion? And (ii) What are the misconceptions, if any, about forces and circular motion as indicated by responses from the questionnaire?

This paper deals only with the second research question mentioned above. A questionnaire (link to the questionnaire is included in the article) was designed in order to probe the understanding of the simple pendulum. It was first piloted with a group of experienced physics teachers from the UK and abroad. Two experienced researchers in physics education were also consulted to enhance the reliability and the validity of the questionnaire. The survey was administered to the cohort of 29 preservice physics teachers undergoing the postgraduate teacher certification programme at one of the teacher education institutions in the UK. The only background information collected was the subject of their undergraduate degree (i.e. major or specialisation). Out of the 29 respondents, 18 mentioned subjects that explicitly involved physics–physics, theoretical physics, physics with mathematics, physics and philosophy. Six respondents had degrees in engineering–electronic engineering, mechanical engineering, medical engineering, aeronautical engineering, and chemical engineering. Three respondents had degrees in geology, natural sciences, and sports sciences, respectively. Two respondents mentioned neither the subject nor the title of their degrees. Three respondents were subsequently interviewed for the purpose of data validation.

The questionnaire was based on the simple pendulum as shown in the figure 1 with labels for different positions of the bob which is swinging repeatedly and freely along the circular arc AB. Position A and B are its extreme positions. Position M is the position where the string is vertical. Position Y is some position between M and B. The participants were instructed to ignore the air resistance to the bob. The questionnaire consisted of 7 questions, henceforth referred to as Q1, Q2, and so forth. Except Q4 and Q6, all other questions were multiple choice questions. Q4 and Q6 were descriptive which sought the respondents' reasoning for their answers to Q3 and Q5, respectively. For the purpose of analysis, the questions were sorted into three question groups whereby each group focused on a different aspect of the bob's motion.

Only 3 respondents out of 29 answered the whole questionnaire scientifically accurately (Czudkova and Musilova 2000, Fitzpatrick 2006). The most revealing answers in terms of the conceptions were obtained from two of the three question groups. Hence these two question groups and the associated findings will be discussed in detail here (figures 2 and 3).

The correct answer for Q3 is option (a), which was chosen by only 7 out of 29 respondents.

The correct answer for Q5 and Q7 is option (e). Only 5 respondents out of 29 answered both the questions correctly.

Different *categories of explanations/reasoning* were identified on the basis of the presence as well as absence of some key phrases/terms in the responses to Q4 and Q6. This strategy made it possible to assert that the different categories of explanations within a given group were mutually exclusive. For example, in the answers in which the respondents explained their reasoning about the direction of acceleration of the bob at the mean position (Q3), the descriptive responses which contained the terms 'force', 'tension', 'gravity', 'weight' or their symbolic/diagrammatic representations were considered as a distinct explanatory category with the interpretation that these respondents thought in terms of the forces acting on the bob. At the same time, those respondents reasoning through forces did not use the terms associated with kinematical or energy-based reasoning. Thus, each category of explanation represented a particular line of reasoning adopted by the respondents.

## Discussion on the respondents' conceptions

### *Association with linear oscillator*

Given that conventionally the simple pendulum is associated with learning simple harmonic motion (SHM) as evidenced by its treatment in most of the textbooks and, indeed, the way it is usually learnt in school, the study recognises the need to locate the responses with respect to SHM. The following points should be noted in this respect-

(a) The questionnaire stated explicitly that the *bob moves along a circular arc*. In addition, the questionnaire also asked the respondents to note that *the pendulum swings through a large angle*.
(b) Considering the pendulum as an instance of SHM should lead to choosing the options (d), (b), and (b) for Q3, Q5, and Q7, respectively (figures 2 and 3). 16 out of 29 respondents chose the option (d) for Q3. However, only 7 of these 16 chose the option (b) for both Q5 and Q7.
(c) Three respondents were later interviewed and asked whether they thought in terms of SHM; all of them stated that they did not. In fact, one of the interviewees recalled noting the mention of the large angle of swing.
(d) None of the respondents mentioned the terms *oscillations, vibrations* or *harmonic motion* in their explanations.
(e) Only 4 out of 29 respondents answered the whole questionnaire in a manner which would be deemed concordant with the SHM view.

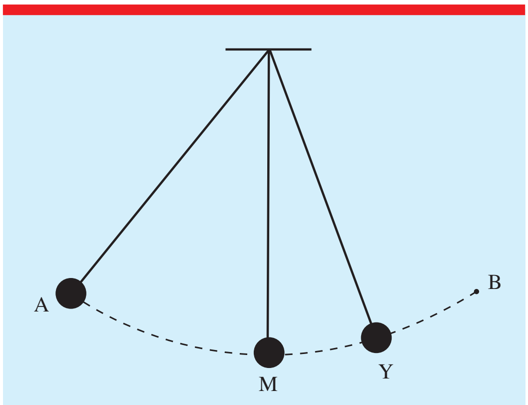



**Figure 1.** The simple pendulum at different positions.

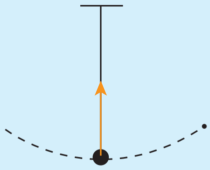
These points indicate that the discussion on the thinking underlying the responses needs to take into account something more than the conventional association of the pendulum with a linear oscillator. These issues will be discussed in what follows.

### *1D approach for 2D problem*

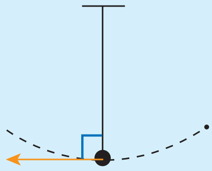
This particular pattern of explanation consisted of invoking the aspects of the *kinematical* concepts of speed, velocity and acceleration *without* using explicitly the notion of forces acting on the bob. There were 8 responses to Q4 (Question Group A, figure 2) that contained the phrases such as 'increasing velocity', 'decreasing velocity', 'direction of motion/travel', and 'magnitude of velocity', whereas while answering Q6 (Question Group B, figure 3), 11 respondents used the terms

**Q.3** Choose the diagram showing the correct direction of the ACCELERATION of the bob when it is at the position M. (**N.B.** There are FIVE options).

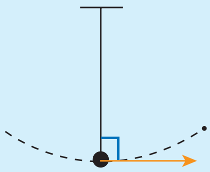
(*a*)



(*b*)



(*c*)



(*d*) The acceleration of the bob at the position M is zero.

(*e*) Either option (*b*) or option (*c*) depending on the direction of the travel of the bob.

**Q.4** Please describe the reasoning behind your choice for the answer of Q.3.

**Figure 2.** Question Group A.

'deceleration', 'decreasing velocity/speed' or explicitly correlated the direction of the acceleration of the bob with the direction of its motion. It should be noted though that not all respondents belonging to the kinematical category in Question Group A maintained this approach in Question Group B, and vice versa.

The choice of the options (c) or (e) for Q3 (Question Group A, figure 2), when taken together with the kinematical ideas used in the reasoning, indicated that these respondents believed that the direction of acceleration had to be either the same or opposite to the instantaneous direction of motion. This would be true only in the case of a 1D motion. Furthermore, the position M (figure 1) is an inflectional point in the motion of the bob considering how its speed changes before and after M. This fact was offered as a reason by some respondents for choosing the option (d) for Q3 (Question Group A, figure 2). The focus on the inflectional nature of the position M implied that these respondents thought only in terms of the speed of a particle without considering the motion's direction while drawing any conclusion regarding its acceleration.

In Question Group B, the respondents who reasoned using the kinematical idea of deceleration chose variously from the options (b), (c), or (e) for Q5, and (b), (c), or (d) for Q7. This class of explanations revealed that the respondents tended to associate acceleration with the change of speed alone, but not with the change in the direction of motion. In fact, the term *deceleration* itself, seen in 5 responses, is illuminating as it conveys only a reduction in the speed of a particle without any association with the change in direction. In this sense, the term deceleration is suitable only for 1D motion.

In summary, it appeared that the respondents offering kinematical reasoning did not take into account the 2D nature of the bob's motion and adopted an analytical approach suitable for 1D motion, where the instantaneous direction of motion and the change in speed could indeed be used to determine correctly the direction of acceleration. It is possible that these respondents were thinking in terms of SHM. But this thinking approach is not reflected consistently in their other answers. These inconsistencies demand some explanation. Extending this line of thought leads to the question of determination of the direction of instantaneous acceleration. The direction of instantaneous acceleration can neither be found by considering the direction of velocity at that instant nor by considering the changes in the speed alone, generally. Instantaneous acceleration can only be found by considering either the instantaneous forces or *two* distinct instantaneous velocities while appreciating the vector nature of velocity. An inadequate grasp of this may manifest itself in a variety of ways, one of which could appear under the guise of 1D analytical approach as demonstrated by these respondents. Thus, even after accounting for the SHM-based thinking, the use of 1D approach calls for an investigation into the teachers' understanding of nature of acceleration.

### *Analysing the forces without understanding the circular nature*

Forces on the bob were analysed by 10 respondents while answering Q3 (Question Group A, figure 2) and 7 respondents while answering Q5 (Question Group B, figure 3) without explicitly referring to the circular nature of the bob's motion. In the Question Group A, these respondents typically drew the free body diagram of the bob and/or described the forces acting on the bob at position M. In the Question Group B, the respondents used the key term 'resultant' or drew a free body diagram of the bob and considered the resultant of the forces acting on the bob while justifying their response to Q5 (figure 3). Some of them attempted to resolve the forces in order to explain their response to Q5. It should be noted though that not all respondents belonging to the forces-based category in Question Group A maintained this approach in Question Group B, and vice versa.

Notably, each of the 10 respondents performing a forces-based analysis in Question Group A (figure 2) chose the option (d) for Q3. They all claimed that the weight of the bob and the tension in the string would balance each other resulting in no net force and, consequently, no acceleration of the bob at M. However, the reason for this balancing was not offered by any respondent. None of these respondents considered that a net centripetal force would be present as the bob was moving on a circular arc. This implies that these respondents failed to take into account the circular nature of the bob's motion. In addition, they demonstrated that there were no tangential forces at the position M, and thus probably understood that there was no tangential acceleration of the bob at M. However, in the case of a two-dimensional (2D) motion, it is possible to have zero tangential acceleration and yet the total acceleration would not be zero, which is exactly what happens at the position M.

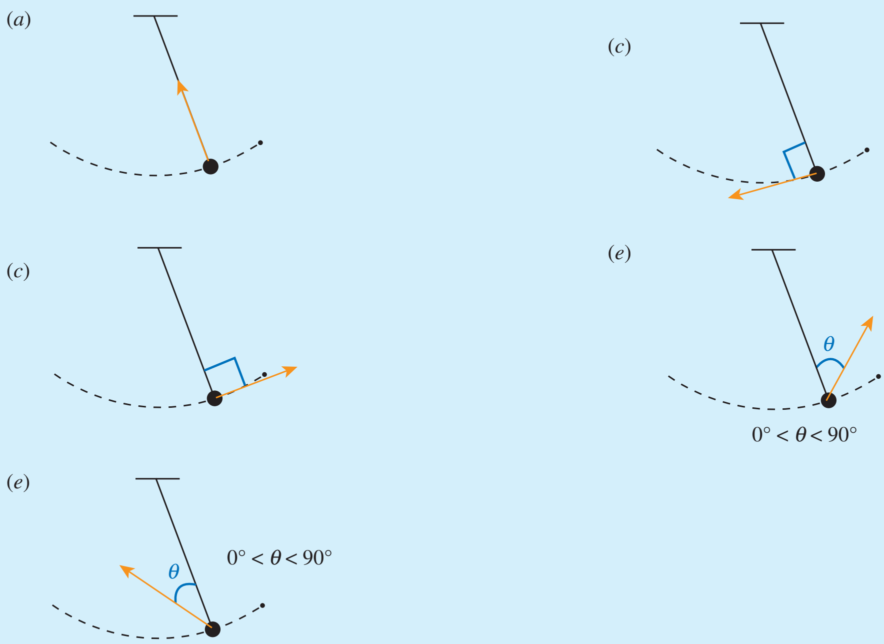
In Question Group B (figure 3), the respondents adopting the 'resultant force' approach as explained earlier chose the options (b), (c) or (e) for Q5, and the options (b) or (e) for Q7. But none of them answered *both* the questions correctly. It should be noted that all the respondents just stated the direction of the resultant force without any detailed, theoretical justification for it. Therefore, the choices of (b) and (c) may be taken to imply that the respondents already presumed a correlation between the net force and the instantaneous direction of the motion of the bob. In other words, there is a possibility that the resultant force was just 'made to fit' the pre-existing correlation they had in mind.

In summary, this discussion shows that an understanding of the individual forces acting the pendulum bob does not necessarily lead to accurate analysis of its motion. The scientifically valid synthesis of these forces would require the appreciation and the understanding of the circular nature of the bob's motion.

### *Appreciating the circular motion of the bob*

There were 7 responses in the Question Group A and 8 responses in Question Group B which explicitly recognised the circular motion of the bob and utilised this recognition in their reasoning. They used of the terms 'circular', 'centripetal', or 'radial' in their answers. Furthermore, these terms were not mentioned in any other explanatory categories. Therefore, it was inferred that these respondents thought in terms of the ideas such as radial or centripetal acceleration/force associated with the circular motion. However, only 6 respondents demonstrated this recognition

**Q.5** Choose the diagram showing the correct direction of the ACCELERATION of the bob when it is at the position Y and travelling RIGHTWARDS.
(**N.B.** There are FIVE options).




**Q.6** Please describe the reasoning behind your choice of the answer for the Q.5.

**Q.7** Consider the Q.5. If the pendulum is going LEFTWARDS, what option would you choose? Please write the letter for the option.

**Figure 3.** Question Group B.

of circular motion in *both* the question groups A and B.

Significantly, in the case of Question Group A, *all the respondents* of this category chose the option (a), the correct answer for Q3 (figure 2), whereas *none of the respondents* belonging to any other explanatory category answered the Q3 correctly. Most significant is the finding that *each of the 3 respondents* who answered the whole questionnaire correctly offered reasoning explicitly based on circular motion, while *none* of the respondents adopting any other reasoning approaches were able to answer the whole questionnaire correctly. This finding corroborates that scientifically correct understanding of the motion of the simple pendulum requires necessarily a grasp of the ideas of circular motion (Czudkova and Musilova 2000, Fitzpatrick 2006). At the same time, some respondents falling in this category were unable to answer the questionnaire correctly. This implies some kind of inconsistency or gaps in their understanding of circular motion or planar motion, in general.

### *Inconsistency in the reasoning strategies*

As noted previously, some respondents while reasoning kinematically in one group indicated that they reasoned by the force-based strategy in the other group. In addition, as described earlier, the association of the pendulum with SHM was not observed consistently in the responses. The inconsistency in the reasoning strategies taken together with the subsequent answers points to the possibility that the respondents may have a low level of understanding of the analytical strategies for solving theoretical problems in physics.

## Conclusions and implications

Only 3 out of 29 respondents responded in accordance with the scientifically accepted way (Czudkova and Musilova 2000, Fitzpatrick 2006). It is worth noting that all the three respondents had university degree in physics. That is, not all the respondents having a degree in physics and *none* of the other degree holders showed the kind of understanding that may be reasonably expected from prospective physics teachers. While the study did not explore the connection between their educational background and their responses, this finding is *prima facie* in line with the findings of multiple past studies of physics teachers that have indicated that a specialisation in physics does not necessarily imply adequate subject understanding (For instance, Preece 1997, Yip *et al* 1998, Kikas 2004.)

On the one hand, the majority of the cohort did not follow the SHM-based analysis consistently. On the other hand, the majority of the cohort did not treat the pendulum as an instance of circular motion either. This is evident from the presence of only a small percentage of the total responses in the exclusive category of the circular motion-based explanation in both the question groups A and B. This indicates the possibility of gaps in the understanding of the simple pendulum or circular motion or both. The absence of acknowledgement of these gaps among future teachers may lead to their perpetuation among the future learners. This questionnaire could be used as the initial step in a more nuanced and thorough exploration of the preservice teachers' understanding of both the pendulum and circular motion.

Furthermore, none of the respondents belonging to an explanatory category other than circular motion could solve the whole questionnaire per the scientifically valid view as demonstrated by Czudkova and Musilova (2000). This supports the argument that the simple pendulum could only be understood scientifically accurately through the analytical apparatus of the circular motion. For an accessible and comprehensive treatment of the simple pendulum as an instance of circular motion, please see Czudkova and Musilova (2000) and Fitzpatrick (2006).

Inadequate analysis of the simple pendulum should also be understood in terms of student teachers' analytical toolbox for 2D motion. The instantaneous acceleration of a particle in a planar motion can always be resolved into its radial and the tangential components. These components have specific and mutually exclusive effects on the motion viz. the radial acceleration is responsible for the change in the direction of motion, while the tangential component changes the speed. The treatment of the simple pendulum through circular motion is an accessible and powerful way for developing the kind of understanding mentioned here. Thus, this study recommends the simple pendulum as a useful tool for exploring and scaffolding the understanding of 2D motion in the context of preservice physics teachers and, indeed, physics learners more broadly.

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## References

Berry A 2012 Pedagogical content knowledge (PCK): a summary review of PCK in the context of science education research *ASE Guide to Research in Science Education* ed J Oversby (Hatfield: The Association for Science Education) pp 29–43

Czudkova L and Musilova J 2000 The pendulum: a stumbling block of secondary school *Phys. Educ.* **35** 428–35

Dobey D C and Schafer L E 1984 The effects of knowledge on elementary science inquiry teaching *Sci. Educ.* **68** 39–51

Fitzpatrick R 2006 The vertical pendulum University of Texas, Austin (http://farside.ph.utexas.edu/teaching/301/lectures/node90.html)

Gess-Newsome J and Lederman N 1995 Biology teachers' perceptions of subject matter structure and its relationship to classroom practice *J. Res. Sci. Teach.* **32** 301–25

Kikas E 2004 Teachers' conceptions and misconceptions concerning three natural phenomena *J. Res. Sci. Teach.* **41** 432–48

Kind V 2012 Science teachers' knowledge of science *ASE Guide to Research in Science Education* ed J Oversby (Hatfield: The Association for Science Education) pp 58–68

Kruger C, Palacio D and Summers M 1992 Surveys of english primary teachers' conceptions of force, energy, and materials *Sci. Educ.* **76** 339–51

Mashood K K and Singh V A 2012a An inventory on rotational kinematics of a particle: unravelling misconceptions and pitfalls in reasoning *Eur. J. Phys.* **33** 1301–12
Mashood K K and Singh V A 2012b Rotational kinematics of a particle in rectilinear motion: Perceptions and pitfalls *Am. J. Phys.* **80** 720–3
Preece P F W 1997 Force and motion: pre-service and practising secondary science teachers' language and understanding *Res. Sci. Technol. Educ.* **15** 123–8
Sanders L R, Borko H and Lockard J D 1993 Secondary science teachers' knowledge base when teaching science courses in and out of their area of certification *J. Res. Sci. Teach.* **30** 723–36
Schwab J J 1978 *Science, Curriculum, and Liberal Education: Selected Essays* ed I Westbury and N J Wilkof (Chicago, IL: University of Chicago Press)
Shulman L 1986 Those who understand: knowledge growth in teaching *Educ. Res.* **15** 4–14
Shulman L 1987 Knowledge and teaching: foundations of the new reform *Harv. Educ. Rev.* **57** 1–22
Trumper R 1999 A longitudinal study of Physics students' conceptions of force in pre-service training for high school teachers *Eur. J. Teach. Educ.* **22** 247–58
van Driel J H, Berry A and Meirink J 2014 Research on science teacher knowledge *Handbook of Research on Science Education* ed N G Lederman and S K Abell (London: Routledge) pp 848–70
Yip D Y, Chung C M and Mak S Y 1998 The subject matter knowledge in physics related topics of Hong Kong junior secondary science teachers *J. Sci. Educ. Technol.* **7** 319–28

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