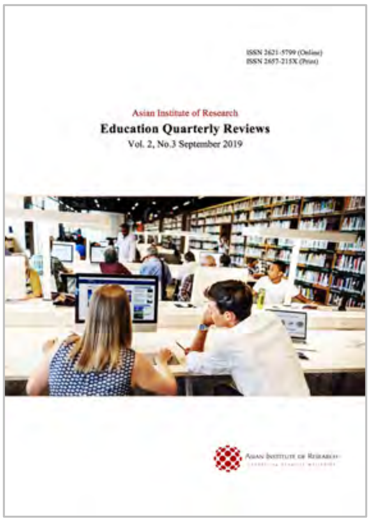

Education Quarterly Reviews

Luchembe, Dennis, and Shumba, Overson. (2019), Practical Work, Simulations and Feedback to Address Undergraduate Physics Students' Challenges in Understanding Circular and Rotational Motion. In: *Education Quarterly Reviews*, Vol.2, No.3, 585-596.

ISSN 2621-5799

DOI: 10.31014/aior.1993.02.03.90

The online version of this article can be found at:
https://www.asianinstituteofresearch.org/

Published by:
The Asian Institute of Research

The Asian Institute of Research
Education Quarterly Reviews
Vol.2, No.3, 2019: 585-596
ISSN 2621-5799

DOI: 10.31014/aior.1993.02.03.90

Practical Work, Simulations and Feedback to Address Undergraduate Physics Students' Challenges in Understanding Circular and Rotational Motion

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Abstract
This analytic paper explores the challenges that undergraduate students face in understanding introductory physics concepts on circular and rotational motion. Challenges are drawn from researchers' own experiences and from the research literature. An innovative method is proposed that combines practical work, PhET simulations, and a systematic feedback and feed-forward process following after the Nicol and Macfarlane-Dick (2006) model. Providing feedback at critical junctures of the teaching and learning process is pertinent for the efficacy of the approach. The experience of implementing the approach suggests positive prospects for efficacy for learning circular and rotational motion by pre-service physics teachers.

Keywords: Feedback, Feed-Forward, Circular Motion, Rotational Motion, Computer Simulations, Practical Work

1. Introduction

This paper presents a conceptual framework and the design of an innovative teaching and learning innovation used with pre-service teachers studying circular and rotational motion. The approach combines practical work, computer simulations, and systematic feedback and feed forward. Feedback employs the principles obtaining in Nicol and Macfarlane-Dick's (2006) model. Learning concepts and quantitative principles concerning circular and rotational motion is well known to be problematic and difficult for many students around the world (Searle, 1985; Roth, McRobbie, Lucas, & Boutonne, 1997). This can be a stumbling block in the appreciation of many applications of these concepts and principles in, for example, the motion of vehicles, planets and in atomic physics.

Student challenges with circular and rotational motion are commonplace. For example, they find it difficult to understand tangential velocity and tangential acceleration and confuse these concepts with those of velocity and acceleration in linear motion (Reif & Allen, 1992; Mashood & Singh, 2012 & 2015; Canlas, 2016). Reif and Allen (1992) observed that students had problems understanding the relationship $a_T = \frac{dv}{dt}$ due to failure to appreciate that instantaneous velocity is tangent to the trajectory resulting in a corresponding tangential acceleration. They experienced problems too with centripetal acceleration $a_c = \frac{v^2}{r}$. Mashood and Singh (2015) suggested this could be a result of lack of differentiation of related but distinct concepts and equations.

Rebello and Rebello (2013) found that students considered angular velocity as being distinct for each particle in a rotating body. This led to failure to appreciate that all points on a rotating discuss travel with the same angular velocity. The above problem is compounded by physics text books that introduce angular velocity of points on a rotating body by starting with the equation: $\omega = \frac{\Delta\theta}{\Delta t}$ and further that $\omega = \frac{v}{r}$. Students failed to appreciate that the equation $v = \omega r$ was only valid for circular motion with a fixed radius. This, according to Mashood and Singh (2015), could be due to a lack of differentiation of related but distinct concepts. Reif and Allen (1992) also found that students fail to discriminate concepts applicable to linear motion, non-uniform motion, and those applicable to uniform circular and rotational motion.

2. Problem statement

The above examples suffice to highlight the conceptual difficulties physics students encounter in learning concepts and quantitative principles of circular and rotational motion. Some of these difficulties are a result of misconceptions on circular and rotational motion, and some a result of a mix up with equivalent concepts in linear motion (Viridi, Mogharabi & Nasri, 2013; Canlas, 2016). It is important to tackle these difficulties, especially during the course of pre-service physics teacher education. Seattha, Yuenyong, and Art-in (2015) and Mashood and Singh (2015) suggest the need for innovative teaching and learning approaches. In the context of a developing country such as Zambia, the need for innovation takes more prominence, given the unavailability of apparatus and equipment for standard experiments. The advent of computer simulations provides a good opportunity to transform learning opportunities for the innovative teacher and his or her students. Jimoyiannis and Komis (2001) observed that "Computer simulations are applications of special interest in physics teaching because they can support powerful modeling environments involving physics concepts and processes" (p. 183). It is important to design instruction that captures this power of computers. As suggested by Jimoyiannis and Komis (2001, computer simulations can help "students confront their cognitive constraints and develop a functional understanding of physics." In order for this to happen, the physics teacher needs to be facilitative to provide guidance and feedback at critical points in the learning activities.

3. Purpose of the research

This paper presents the design of an innovative teaching and learning approach that combines practical work, computer simulations, and systematic feedback and feed forward in learning concepts and principles of circular and rotational motion. The study used PhET Interactive Simulations developed and distributed as freeware by the University of Colorado Boulder (https://phet.colorado.edu/). The students were pre-service physics teachers pursuing the Bachelor of Education degree at Mukuba University in Zambia. The purpose of the paper is, therefore, to introduce the conceptual framework for an innovative teaching approach and to analyse prospects for impact in learning circular and rotational motion when feedback and feed forward at critical points are deliberately incorporated. This effort was part of a doctoral thesis which explored the research question:

> How does the teaching of circular and rotational motion via a systematic combination of feedback, practical work, and computer simulations affect students' learning and attitude towards the topic of circular and rotational motion?

4. Conceptual framework

The rationality for the design of the innovative teaching approach employed in the study lies in the conceptual framework depicted in Figure 1. According to Nicol and Macfarlane-Dick (2006), good feedback practice is quite critical to empower students to become self-regulated learners. Butler and Winne (1995) pointed out that self-regulated engagement with tasks entails, among other things, deliberating about strategies and self-monitoring to ensure learning goals are accomplished. Further to this, both feedback and feed forward are critical in giving 'students the possibility to elaborate on what is not yet understood, get hold of students' misconceptions and engage students in deep learning' (Gamlem & Smith, 2013; p.151). We conjecture that incorporating appropriate feedback and feed forward opportunities work to make the practical work and simulations more powerful learning experiences as suggested by Jimoyiannis and Komis (2001).

The conceptual framework in Figure 1 starts with the preparation of lessons and the identification of critical points in learning the circular and rotational motion. For these to be effectively learned, it is important to create a conducive environment that is interactive and experiential. To achieve this, experiences are provided through practical work and simulations explained in the case study. The interactive environment provided rich opportunities for peer and lecturer feedback and feed forward galvanised by the Nicol and MacFarlane-Dick's (2006) principles. These principles entail the following:

- Clarifying good performance in a manner that makes students appreciate and understand how they are expected to perform on a given task.
- Facilitating the development of self-assessment that increases the ability of students to self-regulate their learning.
- Giving quality written information, feedback on student's performance.
- Encouraging lecturer and peer dialogue to provide oral feedback.
- Encouraging positive beliefs and self-esteem in motivating the learners.
- Providing opportunity to close the gap between student performance and attainment of learning outcomes.
- Requiring lecturers to use the information gathered during lessons to help improve the teaching and learning process.

The external feedback sets up an internal feedback and feed forward process that helps in the attainment of learning outcomes in the affective, cognitive, and psychomotor domains. This internal feedback can assist students self-examine their understanding and self-regulate their learning of concepts and qualitative principles in circular and rotational motion. This expectation of the impact of feedback is borne out of the observation that self-regulated learners use cognitive and metacognitive strategies to regulate their cognition and effort, on for example physics tasks (Achufusi-Aka & Offiah, 2010).

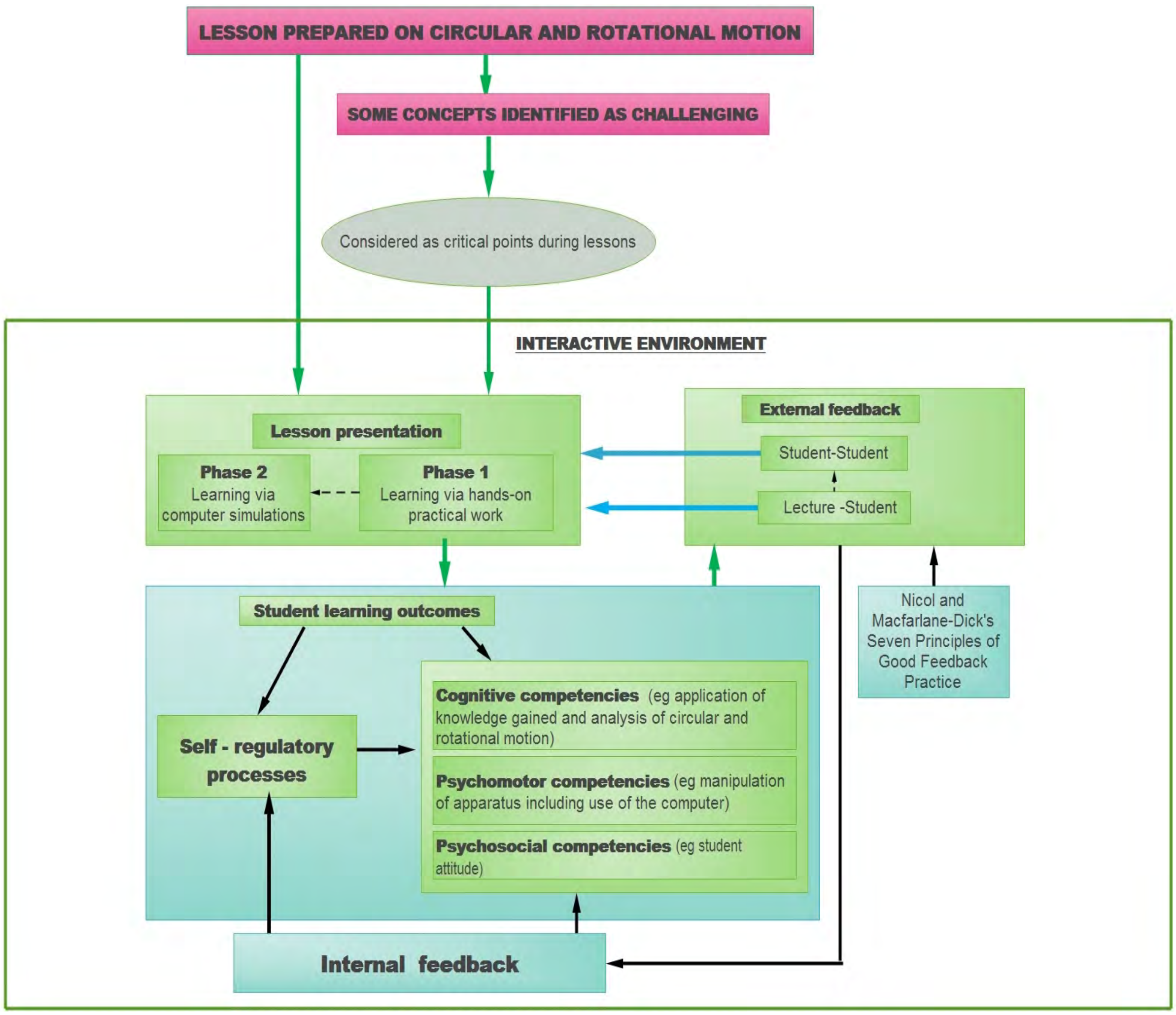


Figure 1. Conceptual framework for the innovative teaching method.

5. Intervention to integrate practical work, computer simulations, and systematic feedback

The conceptual framework in Figure 1 was used in the design of the intervention to integrate practical work, computer simulations, and a systematic feedback as pre-service teachers studied circular and rotation motion. Table 1 summarises and exemplifies the intervention that involved eight 1 hour 20 minutes long lessons. The intervention involved practical work (Phase 1) and computer simulations (Phase 2).

Table 1 shows that pre-service teachers did practical work and simulation activities to achieve specific learning objectives. For example, in the first-week, students in groups of 5-6 conducted practical work using the simple apparatus set up in Figure 2, followed by a simulation in Figure 3. Using the apparatus set up in Figure 2, they explored concepts and qualitative principles involving the relationship between tangential velocity v and radius r. The practical work involved students rotating an object attached to a string. The mass m was rotated horizontally, as shown in Figure 2. Radius r was varied and each time the corresponding circumference calculated. The periodic time T was determined, and the corresponding velocity v calculated. Oral feedback in the last column of Table 1 was centered on this concept. It helped the lecturer scaffold the practical activities.

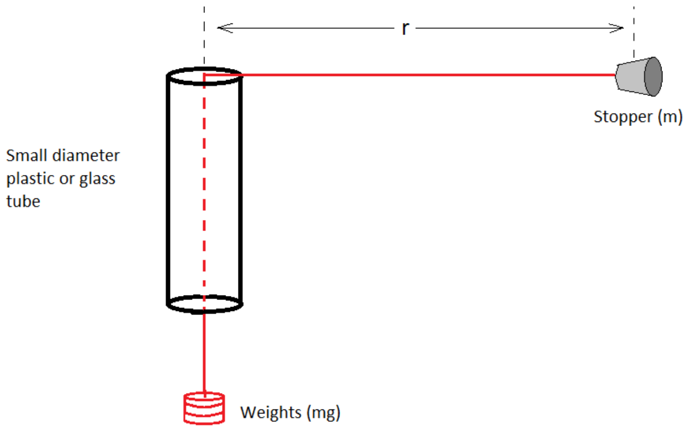


Figure 2. Simple rotational apparatus

Table 1. Summary description of lesson presentations

Phase	Learning objectives	Lesson description and purpose	Feedback
Week 1: Practical work #1	Determine the relationship between tangential velocity v and radius r. Students should be able to discuss the equation $a_T = \frac{dv}{dt}$. Derive the equation $a_c = \frac{v^2}{r}$.	Practical work one was carried out to help students understand the relationship between r and v_T. The lesson helped discuss tangential velocity and acceleration so that learners would not confuse the two terms with the everyday use. Understanding of tangential velocity prepared students for lessons on the angular velocity. Student understanding of these concepts was gauged by the response they gave to the end of lesson task, which required them to derive the equation to show the relationship between v and r.	For oral feedback, focus students on describing the direction of mass m as it rotates. Give appropriate feedback after asking the group to explain the meaning of the equations $a_T = \frac{dv}{dt}$ and $a_c = \frac{v^2}{r}$. For written feedback, focus on the student's description of the relationship between v and r. Students may show the relationships such as $v = \omega r$. Accept such equation but guide the student also to consider the relationship, $a_c = \frac{v^2}{r}$
Week 1: Practical work #2	Determine the relationship between variables in the equation; $F_c = \frac{mv^2}{r}$	Practical work one and two were combined because the same apparatus and measurements were used for both practical activities. The centripetal force F_c was introduced. The practical work also prepares students for tension force for a vertical plane. End of lesson task for this activity was designed to find out if students could apply quantitative principles they had learned.	When students start applying the equation $F_c = \frac{mv^2}{r}$. Ask them to explain the relationship between variables in the equation. Provide appropriate feedback (For written work or oral discussion).
Week 1: Simulation #1	Differentiate speed and tangential velocity. Differentiate tangential velocity and angular velocity.	Apart from helping students simulate what was learned in practical work one. Simulation one helped reduce the misconception that angular velocity is distinct for each particle in a rotating body. The activity was used to demonstrate that; $v = \omega r$ This equation helped show the relationship between v and r. The end of the lesson task's aim was to help monitor student's understanding of the concept of angular velocity ω and its relationship to v and r.	Ask the student to explain the meaning of the equation $v = \omega r$ and to give appropriate feedback. For written feedback, note that the feedback that was provided under task for practical work one was expected to help students in a task for simulation one. Note student's description of the relationship between v and r and provide appropriate feedback to help students understand the relationship between r and ω

Table 1. (Continued)

Week 1: Simulation #2	Describe the relationship between the direction of centripetal acceleration and tangential velocity.	The main focus for this simulation was to discuss the direction of centripetal acceleration and tangential velocity. The activity also helped students prepare for simulation on centripetal force. End of lesson task for simulation two was given to find out if students understood the relationships amongst a_c, v, and F_c.	Focus on seeing student understanding of the direction of centripetal acceleration and tangential velocity after using simulations. Give appropriate feedback to responses. See also that students discuss and correctly indicate the directions of tangential velocity, centripetal acceleration, and centripetal force. In each case, give feedback. This applies to student oral and written responses.
Week 2: Simulation #3	Justify the relationships amongst centripetal acceleration a_c, tangential acceleration a_T, and total acceleration a_{tot}	The simulation helped students explore the relationships amongst variables in circular and rotational motion. It, for example, helped students understand equations such as $a_{tot} = \sqrt{a_T^2 + a_c^2}$. It was expected that through exploration, students were able to differentiation-related but distinct concepts in circular and rotational motion.	See that students discuss and correctly use the quantitative principle to find tangential and centripetal components of acceleration. They must also show understanding of the use of a_T and a_c to find total or magnitude of the acceleration. Use appropriate feedback which focuses on the use of these concepts to find the total or magnitude of acceleration. This applies to oral and written responses.
Week 2: Simulation #4	Explain how frictional force helps keep an object in a circular path. Show the relationship amongst coefficient of friction, velocity, and angle of inclination.	Demanded students to explain how centripetal force caused an object to go round a curved path. Students used simulation to familiarised themselves with the importance of equations such as $F = \frac{mv^2}{r}$, $f_s = \mu_s F_N$ and $v = \sqrt{\mu_s r \tan\theta}$. The task for simulation four tested student understanding of centripetal force, velocity, and skidding.	Give appropriate feedback after asking the group to explain how frictional force helps keep an object in a circular path. Written feedback must also consider the same concepts.
Week 3: Practical #3	Explain the effect of mass distribution on an object's motion	Practical work three was a simple hands-on practical work to learn and prepare for concepts involving equations such as $I = \sum mr^2$. It helped students understand the relationship between mass distribution and the moment of inertia.	Focus students on observing and discussing the effect of mass distribution on an object's motion. Give students appropriate feedback on this concept.
Week 3: Simulation #5	Analyse the effect of mass distribution on the moment of inertia. Use the equation $I = \sum mr^2$.	Simulation five was conducted to explore the relationship between mass distribution and the moment of inertia. The task for simulation five was made up of conceptual questions which focused on testing student understanding of the effect of mass distribution on the moment of inertia.	Ask students to explain the equation $I = \sum mr^2$. Give students appropriate feedback in connection with these concepts and quantitative principles.

For example, the critical moment comes after students had measured r and found T. They were first asked to explain the purpose of taking these measurements. In order to address the understanding of tangential velocity, students were asked to identify the direction mass m would take if the string was suddenly cut. This was the starting point to use feedback on this pre-identified critical point. Depending on student responses, the lecturer's responsibility was to provide feedback that could guide students towards the learning objective by helping them observe that the direction of mass *m* was changing with time. This was the moment to help students discuss in their groups the relationship between *v* and *r*.

In order to enhance self-regulation, instructions given in the laboratory manual were used just as a guide, and students were not penalised for any improvisation that was safely done. For example, some groups had short strings. Instead of starting with *r* of 1.5m as indicated in the laboratory manual, students in some cases started with 1.2m. Feedback from the lecturer was given to encouraged learners to develop independent learning. The groups were, therefore, informed that 1.2m was another good choice for the initial length of *r*.

Another critical point that requires feedback and feeds forward, in this case, was the identification of the relationship between *r* and *v.* When the lecturer noted that students had challenges identifying the relationship, a question was posed to initiate group discussion. This was to encouraged lecturer and peer dialogue as supported by Nicol and Macfarlane-Dick's (2006) fourth principle of good feedback practice. Each time a question was posed, students were left to discuss it. This was done so that through student-student feedback, learners could acquire a deep understanding of the topic.

After discussing this relationship, the emphasis turned to concepts of tangential acceleration a_T and centripetal acceleration a_c. Basing on concepts from tangential velocity, the lecturer asked questions and initiated the feedback and feed forward process to help students define a_T and discuss the equation $a_T = \frac{dv}{dt}$.

Table 1 shows too the sample of simulation activities conducted, e.g., the simulation activity that followed the practical work. Figure 3 shows a screenshot of the PhET simulation activity that was used in simulation one (accessed from https://phet.colorado.edu/en/simulations/category/physics).

Using the simulation activity, students determined the radius *r* of rotation and the corresponding tangential velocity *v* displays on the screen. Radius *r* was measured using the ruler, which is displayed across the rotating disc. The velocity-time graph, including the value of the velocity in m/s was also displayed on the screen. The value of *r* was changed and the procedure repeated. Each time students noted the corresponding value of *v* displayed on the screen. Critical points similar to those which were identified when learning via physical hands-on practical work were utilised during this phase. As earlier discussed, understanding the relationship between *v* and *r* was still a critical moment for this phase. It required guidance through feedback and feed forward.

Angular velocity ω was introduced during simulation one. Students related the value of *r* to ω at different points on the rotating circular disc. The critical point came after students recorded four values of *r* and the corresponding ω. At this moment, the lecturer initiated oral feedback and feed forward, and asked the group to explain the relationship between *r* and ω.

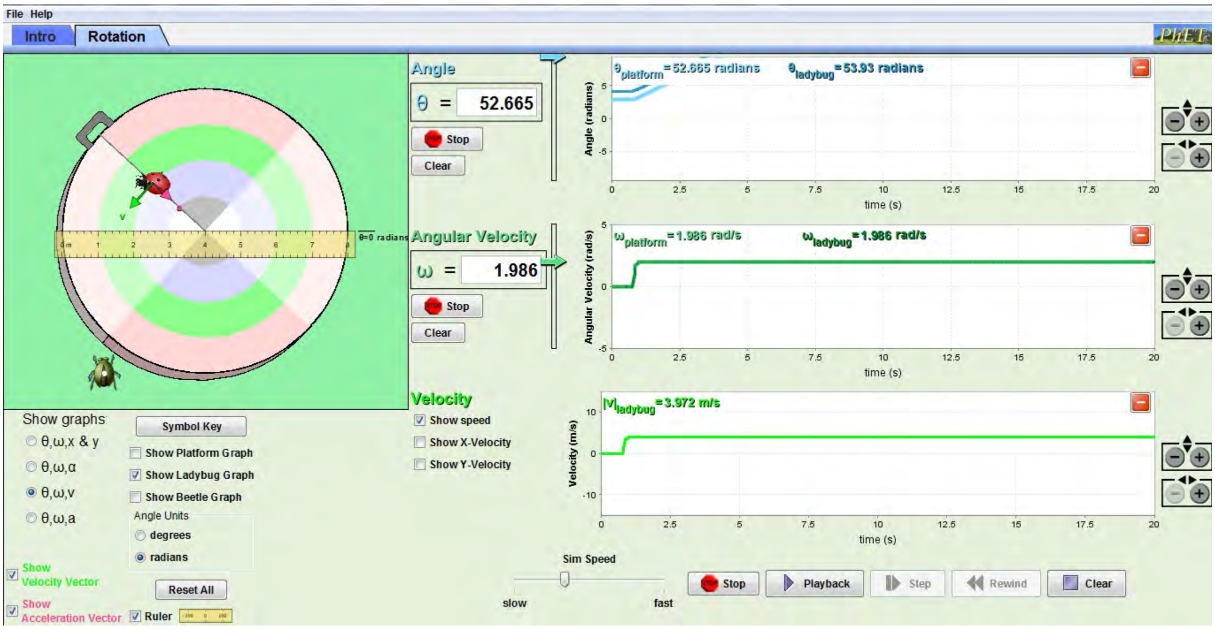


Figure 3. Screenshot of a PhET computer simulation

In order to enhance the process of feedback, the lecturer asked questions to the group centered on the meaning of the equations $\omega = \frac{\Delta\theta}{\Delta t}$ and $\omega = \frac{v}{r}$. The lecturer provided feedback to student's responses. Basing on concepts learned, students were asked to define angular velocity. The simulation activity ended with students answering the questions in Box 2.

6. Prospects for the impact of the intervention

This paper explores too the impact of the intervention following the work of pre-service teachers after completing the tasks in Box 1 (post-practical work) and Box 2 (post-simulation). These tasks were meant to assess understanding of concepts and quantitative principles discussed during the lessons.

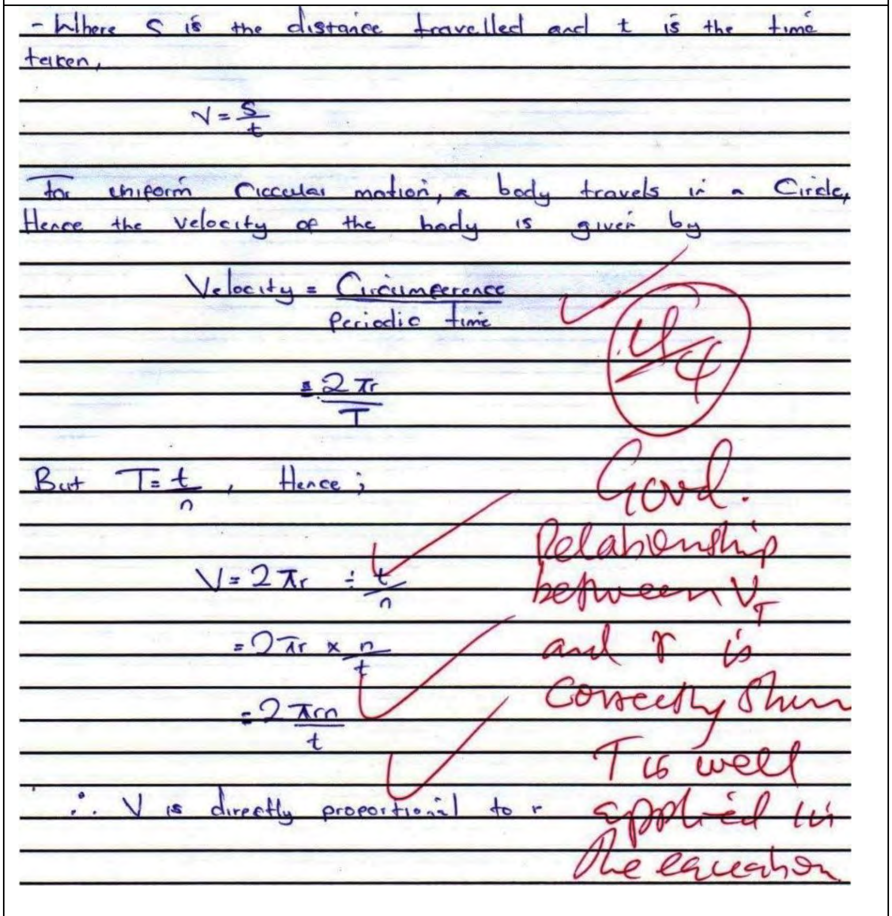
Box 1: Task for post-practical work

Using the ideas gathered in your practical work, formulate an equation which describes the relationship between velocity and radius. You must show all the steps.

Figure 4 shows a sample of written responses for a successful and for an unsuccessful student, respectively. In both cases, students were given written feedback in the form of detailed comments. For example, the comment given to the unsuccessful student was meant to highlight the concepts that the student failed to show in the equations. The focus was on the task and not the student in the hope to encourage positivity and recognition of error. The feedback for the successful student identified with successful elements in the task, i.e., 'Good. Relationship between v and r is correctly shown. T is well applied in the equation'. Unsuccessful students were allowed to re-submit corrected work.

Box 2 shows the task assigned to students following the PhET simulation experience. Figure 5 and Figure 6 show a sample of written responses by the students whose work was presented in Figure 4 (post-practical work). Figure 5 shows the work of the student who was unsuccessful in Figure 4; the student successfully responds to the post-simulation assignment. In both cases, students were given written feedback in the form of detailed comments. The student correctly shows the relationship between v and r.

Successful solution



- Where S is the distance travelled and t is the time taken,

$v = \frac{S}{t}$

For uniform circular motion, a body travels in a circle, Hence the velocity of the body is given by

$\text{Velocity} = \frac{\text{Circumference}}{\text{Periodic time}}$

$= \frac{2\pi r}{T}$

But $T = \frac{t}{n}$, Hence;

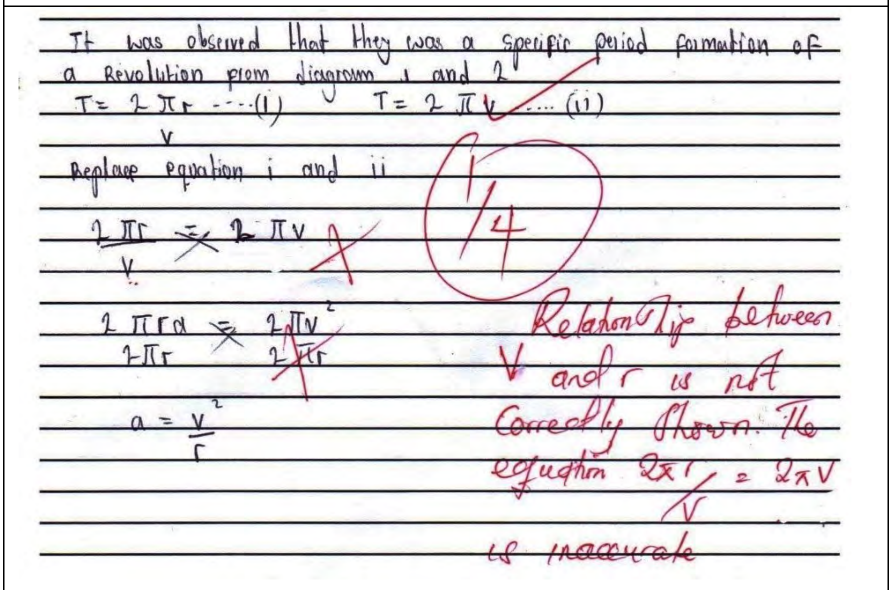
$V = 2\pi r \div \frac{t}{n}$

$= 2\pi r \times \frac{n}{t}$

$= \frac{2\pi r n}{t}$

∴ V is directly proportional to r

Unsuccessful solution



It was observed that they was a specific period formation of a Revolution from diagram 1 and 2

$T = \frac{2\pi r}{v}$ ---(i) $T = 2\pi v$ ....(ii)

Replace equation i and ii

$\frac{2\pi r}{v} = 2\pi v$

$\frac{2\pi r a}{2\pi r} = \frac{2\pi v^2}{2\pi r}$

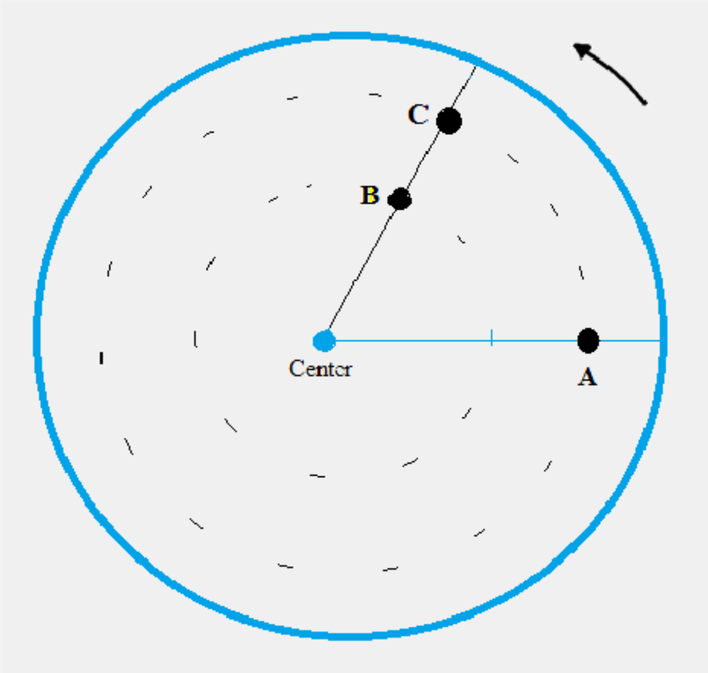
$a = \frac{v^2}{r}$

Figure 4. Sample written responses for a successful and unsuccessful student.

Box 2: Task post-simulation

1. Describe the relationship between radius and speed of rotation.

2. The figure below shows a circular disc rotating in the direction indicated by the arrow. Points A, B, and C are marked on the surface of the disc that is rotating at tangential velocities v_A, v_B and v_C respectively.



Which of the following relationship is correct about these three velocities?

A. $V_c = V_B > V_A$; B. $V_c = V_A > V_B$; C. $V_c > V_B > V_A$; D. $V_c = V_B = V_A$

3. Explain the reason for your answer to question (2).

4. Which of the following relationship is correct about the angular velocity of points A, B and C.

A. $\omega_c = \omega_B > \omega_A$; B. $\omega_c = \omega_A > \omega_B$; C. $\omega_c > \omega_B > \omega_A$; D. $\omega_c = \omega_B = \omega$

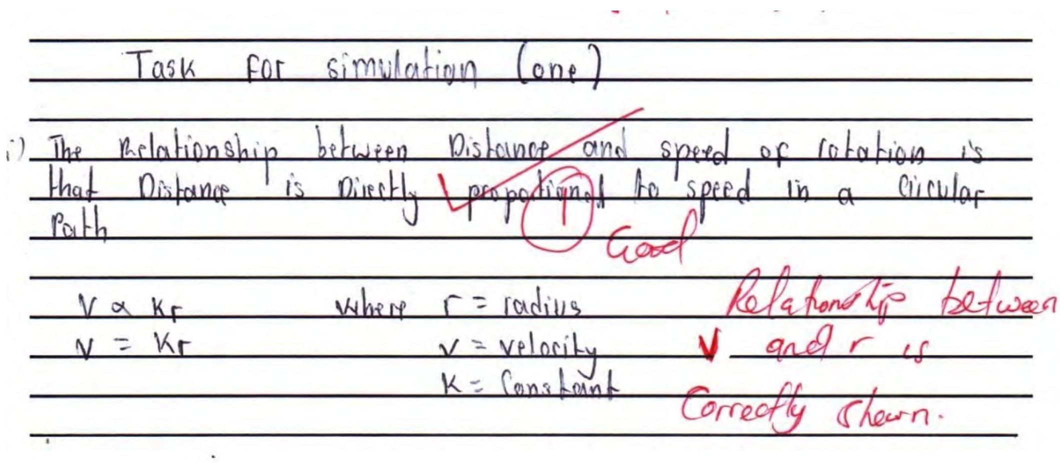


Figure 5. Sample written response post-simulation by former unsuccessful student

Figure 6 is of the student whose work was 'successful' in Figure 4; the student correctly gives the relationship between *v* and *r*.

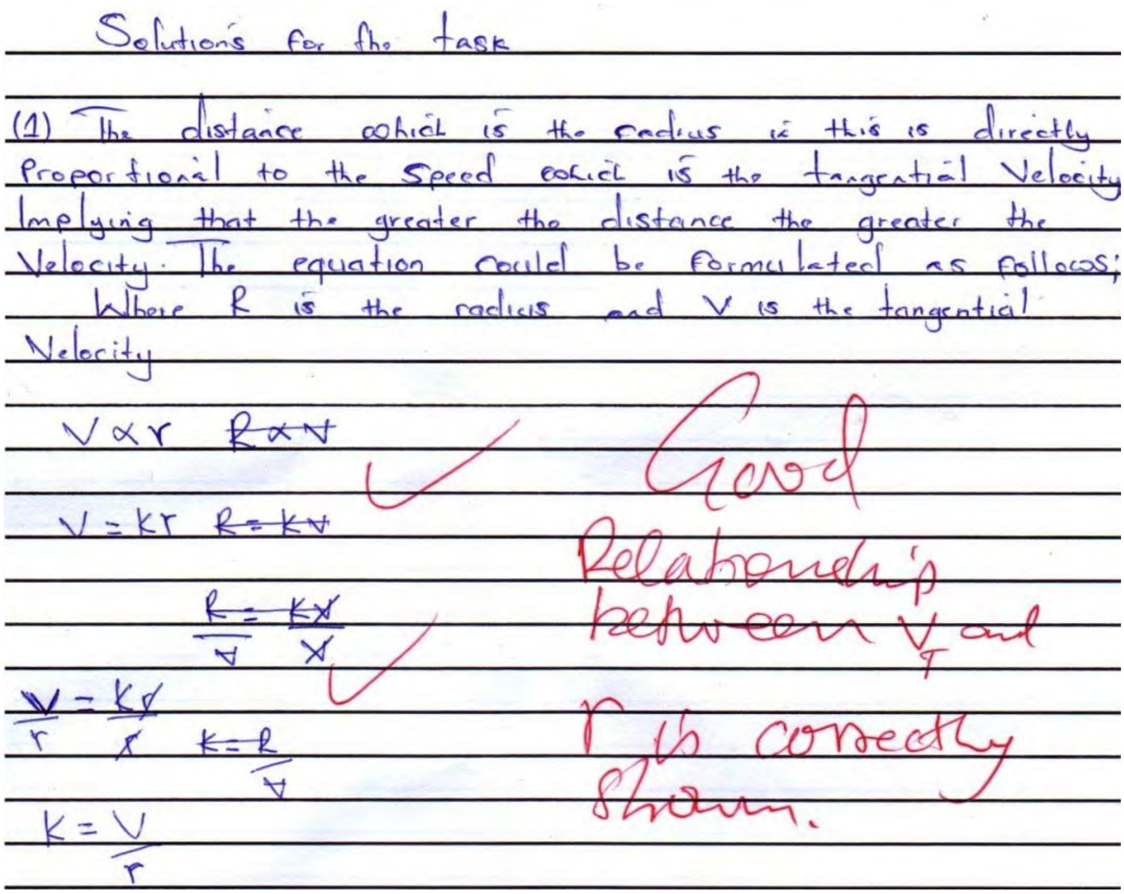


Figure 6. Sample written response post-simulation by formerly successful student

7. Discussion

The experiences reported above point to the potential innovation and impact of integrating practical work, computer simulation, and systematic feedback for conceptual mastery among pre-service physics teachers. As shown in previous studies, a combination of simulations and practical work positively impacted the learning of topics such as mechanics, waves and optics, and thermal physics (e.g., Zacharia & Anderson, 2003). With reference to the conceptual framework presented here, this combination of activities yields the possibility of enhancing the development of competencies in all domains, cognitive, psychomotor, and affective. The computer simulations allowed students to explore the topic by changing variables and observing the outcomes (Moser, Zumbach & Deibl, 2017). They experimented and observed the results.

However, the value added by practical work and simulations will only be maximised through the provision of systematic feedback as the students work. Hattie and Timperley (2007) noted that when given correctly, the feedback has the potential to improve learning and will help students self-regulate their learning and to reflect on why they are doing particular tasks. As rightly observed by Achufusi-Aka and Offiah (2010), self-regulated learners in physics lessons tend to use cognitive and metacognitive strategies to regulate their cognition and effort, leading to better concept acquisition and mastery. In this study, pending the qualitative results of the study, the Nicol and Macfarlane-Dick (2006) model are proposed to be a useful and relevant model to achieve effective feedback and feed forward in learning difficult concepts in physics among pre-service teachers.

8. Conclusion

The paper flags out some of the challenges faced by undergraduate physics students when learning the circular and rotational motion. It devises a conceptual framework and explains the teaching and learning intervention that involved practical work, simulations, and critical moments for feedback and feed forward. While the results are pending analysis, use of internet-based resources such as the PhET simulations and practical work with feedback provided at critical junctures of teaching and learning, are conjectured to impact the learning of abstruse concepts such as those associated with circular and rotational motion.

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