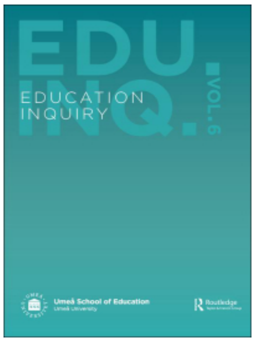

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In-service physics teachers' content knowledge: a critical reflection on the case of the upthrust concept

Yashwantrao Ramma [a*], Ajeevsing Bholoa[a] and Mike Watts[b]

[a]Mauritius Institute of Education, Mauritius; [b]Brunel University London, UK

ABSTRACT

Physics educators must possess a strong foundation in content knowledge to effectively promote scientific inquiry-based learning in line with the national curriculum goals. However, factual, conceptual, and procedural knowledge gaps can impede meaningful teaching and learning of Physics. This study explores the use of the Predict-Observe-Explain (POE) model to assess in-service Physics educators' understanding of "Upthrust." The research involved 23 participants from a professional development programme in Mauritius. Data were collected through task-based worksheets and focus group discussions and validated using Rasch modelling. The findings indicate that while educators are somewhat familiar with Upthrust, their knowledge must be improved for making accurate predictions and providing detailed scientific explanations, particularly when disparities between predicted and observed outcomes occur. Additionally, educators' reliance on formula-driven methods, influenced by their limited exposure to experimental practices, underscores the need for change. This study underscores the importance of fostering conceptual understanding over memorisation in Physics education. By challenging and broadening the beliefs of prospective Physics educators and promoting inquiry-based teaching, these efforts can significantly enhance Physics education, student engagement, and achievement in secondary schools in Mauritius.

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Upthrust; predict-observe-explain; rash model; inquiry-based learning

Introduction

Compelling evidence suggests that the quality of education is closely tied to the quality of the teaching force (Papanthymou & Darra, 2023; Yao & Lin, 2023). As globalisation and digitalisation continue to reshape society, education is crucial in equipping citizens with the necessary skills and knowledge to navigate these changes and become lifelong learners. The United Nations' Sustainable Development Goal 4 (SDG 4) aims to foster inclusive, equitable, and high-quality education for all while promoting lifelong learning opportunities (UNESCO MGIEP, 2017). To achieve this goal, one of the UN's target indicators for 2030 is to increase the number of qualified teachers

CONTACT Yashwantrao Ramma y.ramma@mieonline.org Mauritius Institute of Education, Mauritius
*Present address: Université des Mascareignes, Rose Hill, Mauritius.

who have undergone proper pedagogical training, particularly in developing countries and small island developing states. However, despite rapid digital evolution, the quality of education still needs to catch up due to deficiencies in teacher competencies and learning environments (Canuto et al., 2024). There have been widespread proposals for significant changes to how teaching and learning occur in classrooms across numerous countries. However, the extent to which these changes occur remains to be determined. In educational reform, teacher education and professional development are recognised as critical drivers for improving teacher knowledge and student progress (Haug & Mork, 2020; Tran et al., 2020). Despite this recognition, research studies on teacher knowledge and its implications for teacher education programmes are scarce, and some downplay the importance of content knowledge, assuming that in-service teachers already possess the necessary content knowledge (Guler-Nalbantoglu & Aksu, 2021).

In this paper, "content knowledge" refers to knowledge of the subject matter and its organising structures (Shulman, 1986). Various studies have shown that incorporating modules focused on deep content knowledge during teacher education can place equal emphasis on teachers' content knowledge and pedagogical content knowledge (Bayram-Jacobs et al., 2019; Blomeke et al., 2014; Kleickmann et al., 2017). However, it is essential to note that pedagogical content knowledge is highly dependent on content knowledge, regardless of the subject area. Furthermore, most studies on teacher content knowledge have focused on pre-service teacher education programmes rather than in-service teachers. The current study aims to address this gap in the literature by examining the content knowledge of practising/in-service Physics teachers who hold a bachelor's degree in Physics. This study explicitly investigates teachers' comprehension of the concept of upthrust, a topic taught at the Higher School Certificate level (age 17–18) in Physics, and their proficiency in connecting and elucidating essential Physics principles through the analysis of experimental data. The motivation for the study stems from the concerns and apprehensions of the authors, who are teacher educators, regarding the content knowledge of in-service Physics teachers (Ramma et al., 2017).

The research presented in this study is situated within the context of Mauritius, a small island developing state where Physics Education plays a critical role in the broader national education system. The Mauritian education framework, particularly at the secondary level, emphasises a curriculum (NCFS, 2009) aligned with international standards, yet it faces unique challenges related to resource availability, teacher training, and student engagement. Physics teaching in Mauritius is heavily influenced by the need to prepare students for high-stakes examinations, which often leads to a focus on rote learning and formulaic approaches rather than deep conceptual understanding. This study examines these dynamics by exploring how in-service teachers in Mauritius grasp fundamental Physics concepts, specifically upthrust, and how this understanding impacts their teaching practices.

By situating the research within this context, the study highlights the challenges Mauritian Physics educators face and provides insights that apply to similar educational settings globally. In the conclusion and discussion, we revisit the implications of these findings, emphasising their relevance both within Mauritius and in different contexts where similar educational conditions exist. The study contributes to the broader discourse on Physics Education by demonstrating how targeted professional development can address gaps in teacher knowledge, ultimately leading to improved student outcomes in Mauritius and comparable educational systems worldwide.

Literature review

It is widely agreed that effective teaching requires teachers to have a strong command of the content within their respective fields (Cekbas & Kara, 2009; Hill et al., 2005; McArdle, 2010; Ramma et al., 2014). Additionally, they must also demonstrate robust pedagogical content knowledge and the skills necessary to implement instructional strategies that promote higher-order thinking skills in students (Borko, 2004; Ramma et al., 2015; Razak et al., 2023; Seidel & Shavelson, 2007). Etkina (2010) emphasises the significance of deep content knowledge (CK) as a fundamental requirement for the development of pedagogical content knowledge (PCK) among Physics teachers. As Hobbs and Porsch (2021) aptly pointed out, teachers with inadequate content knowledge tend to be constrained in their instructional choices, often relying on traditional approaches that involve presenting a set of rules and procedures for students to follow. In Physics Education, the tendency is to teach the Physics content knowledge using a variety of pedagogical approaches and by relating experimental data with theory and vice versa in the process of scientific reasoning and argumentation. However, achieving this instruction level requires teachers to receive professional support tailored to their specific needs (Graham et al., 2020). Teacher education and professional development programmes are essential for teachers' CK (Schiering et al., 2023). Several teacher education programmes are designed in ways that include elements of CK that new teachers receive during their professional development programme (Darling-Hammond, Schachner, Wojcikiewicz, & Darling-Hammond et al., 2024, Boyd et al., 2009). However, the extent to which teachers' CK has been investigated has remained relatively elusive.

Etkina (2010) highlights the importance of deep CK as a prerequisite for developing PCK among Physics teachers. There is compelling evidence that teachers need to have rich, connected understandings and CK in their subject matter to promote the construction of meaningful knowledge structures in their students (Boyd et al., 2012; König et al., 2024; Spangenberg, 2021). Several studies have emphasised the necessity for teachers to possess strong content knowledge as a foundation for demonstrating adequate pedagogical knowledge and pedagogical content knowledge (Großschedl et al., 2015; Kleickmann et al., 2017; Rollnick, 2017). This vital content foundation enables teachers to convey subject matter effectively and adapt their teaching strategies to meet diverse student needs. When teachers have a deep understanding of the subject matter, they are better equipped to anticipate student misconceptions, provide more straightforward explanations, and design more engaging and meaningful learning experiences.

Content knowledge is a fundamental aspect of PCK, representing the essential fusion of subject matter expertise and teaching methods necessary for effective instruction. Educators possessing strong content knowledge are better equipped to employ pedagogical strategies that enhance student engagement and comprehension. They effectively connect disparate concepts, utilise relevant examples, and implement suitable teaching techniques aligning with students' knowledge and experiences. This integration of content and pedagogy fosters a more enriching learning environment, enabling teachers to facilitate deeper understanding and a greater appreciation for the subject matter (Shulman, 1986).

In contrast, teachers with weaker content knowledge may need help to explain concepts clearly, often resorting to rote teaching methods that limit student engagement and understanding. This reliance on traditional approaches can impede the development of students' critical thinking and problem-solving skills, which are crucial for deeper learning (Hill et al., 2005; van der Zanden et al., 2020). Therefore, ongoing professional development that strengthens teachers' content knowledge is vital for fostering high-quality teaching and learning in the classroom.

One pedagogical practice that encourages a shift away from traditional approaches and fosters active student engagement in science activities is the Predict-Observe-Explain (POE) model (Crouch et al., 2004; Özcan & Uyanik, 2022). The POE approach aligns with the constructivist perspective on learning, emphasising that knowledge is actively constructed through experience and interaction with the environment. Although it shares an epistemological foundation with inquiry-based learning, the POE approach is distinct in that it is a simplified version of inquiry-based learning and teacher-guided and follows a more structured, linear progression within the lesson (Liew & Treagust, 1995; Wei He et al., 2021).

The POE approach facilitates scientifically oriented thinking, dialogue, and problemsolving processes and provides a basis for further scientific exploration. Several research studies support the effectiveness of the POE model in the teaching and learning of Science by relating it, for example, with Piaget's concept of accommodation, conceptual change, probing misconceptions (Nadelson et al., 2018), and metacognition (Stanton et al., 2021).

Conceptual framework

Two models guide this study. Firstly, we have employed Shulman's model of teacher knowledge (Shulman, 1986) to construct a comprehensive framework (Figure 1). This framework encompasses various elements, from acquiring academic content knowledge (in Physics) to achieving adequate student learning outcomes. While some studies have demonstrated a direct positive correlation between teacher knowledge and student achievement (Baumert et al., 2010; Darling-Hammond, 2003; Darling-Hammond & Young, 2002), other studies (Akiri, 2013; Nye et al., 2004) have been inconclusive about the existence of such a relationship. Furthermore, research studies have indicated that a significant number of university students and graduates possess misconceptions regarding Physics concepts and experience difficulties in solving higherorder Physics problems (Marušić et al., 2011), which are impeded by their intuitive knowledge (Sherin, 2006).

Secondly, we employed the Predict, Observe, Explain (POE) model, a well-established approach in science education research, to investigate the teachers' understanding of upthrust. Figure 2 provides a schematic overview of how the POE model was implemented in our study.

The POE model, developed by White and Gunstone (1992), is structured into three distinct phases: Prediction, Observation, and Explanation.

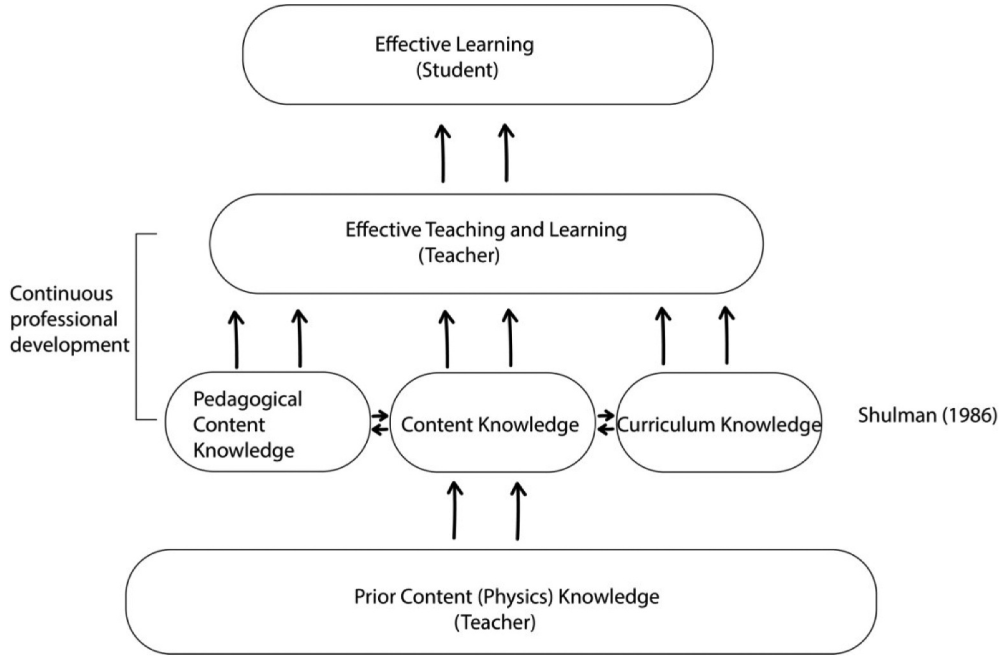


Figure 1. Effective teaching and effective learning.

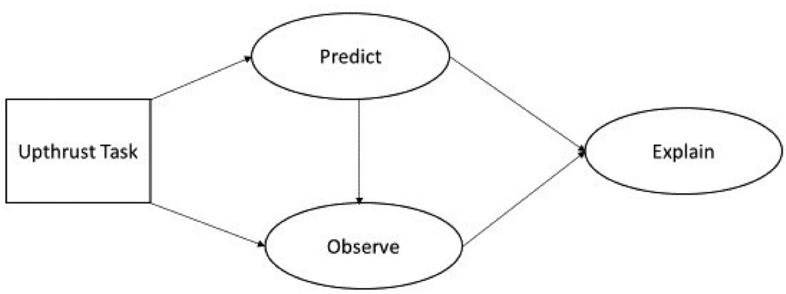


Figure 2. Implementation of the POE model.

(1) **Prediction Phase**: In the first phase, participants are asked to make predictions about a specific event – in this case, the behaviour of objects related to the concept of upthrust. Teachers were required to use their prior content knowledge to predict what would happen in each Physics scenario, justifying their predictions. This phase is crucial because it reveals the teachers' initial understanding and any preconceptions they might have about the concept.
(2) **Observation Phase**: The second phase involves direct interaction with a real-world experimental setup. Participants were required to perform practical tasks in the laboratory setting, where they could observe the actual outcomes of the experiment. The teachers could compare their predictions with real data by engaging directly with the experiment. This hands-on experience is essential as

it challenges the participants to reflect on their initial predictions when confronted with empirical evidence.

(3) **Explanation Phase**: In the final phase, participants were asked to reconcile any discrepancies between their predictions and their observations. They needed to explain any differences, using Physics-based reasoning to justify their revised understanding. This phase helps solidify correct conceptual knowledge and identifies and addresses any remaining misconceptions.

Figure 2 encapsulates these three phases sequentially, demonstrating how each phase logically follows the previous one to deepen the participants' understanding of the concept. The sequence emphasises the structured nature of learning in science, where initial predictions lead to observations and these observations, in turn, inform the final explanations.

Furthermore, our approach in this study went beyond simple observation. By involving the teachers in practical tasks, we ensured they confronted their experimental data, making the learning process more impactful. The conversational interviews conducted in the third phase were particularly insightful, as they provided a window into how the teachers used scientific reasoning to resolve conflicts between their predictions and the observed outcomes.

Overall, the POE model, as depicted in Figure 2, served as a robust framework for examining the depth of teachers' understanding and identifying areas where further development in their content knowledge was needed.

Method

Research approach

This study used a mixed-method research approach that reflects a pragmatic paradigm. Research conducted in naturalistic settings, such as the classroom, should prioritise selecting methods and tools for data collection that best address the research questions rather than solely relying on qualitative or quantitative research paradigms (Tashakkori & Teddlie, 2003). Different research designs can be employed in mixed-methods research (Cresswell & Clark, 2011). In this study, a convergent mixed-method design was chosen. It involved the concurrent integration and comparison of quantitative and qualitative data to enhance our understanding of in-service Physics teachers' content knowledge concerning "upthrust" and its associated concepts, along with their ability to construct conceptual arguments when presented with experimental data. We hypothesised that for learners to develop a rigorous conceptual understanding, i.e. effective learning, teachers should have acquired good content knowledge during their undergraduate studies at the university level, as well as sound PCK, which includes curricular knowledge during teacher training (refer to Figure 1). In our analysis, content knowledge has been determined through the lens of factual, conceptual, and procedural knowledge. Factual knowledge of upthrust refers to knowledge of terminology, facts, or bits of interrelated information. The conceptual knowledge of upthrust is assessed by examining implicit and explicit responses that pertain to understanding concepts (Rittle-Johnson & Schneider, 2014; Star & Stylianides, 2013). In addition, the responses should reflect a direct relationship with upthrust and its correct meaning. Procedural knowledge, which is goal-oriented, facilitates problem-solving behaviour (Braithwaite & Sprague, 2021; Star & Stylianides, 2013) and has been analysed within logical, analytical, and drawing conclusions following teachers' engagement with experimental work. We narrowed the focus of our study by formulating the following research questions:

1. To what extent do in-service Physics teachers have adequate knowledge of "upthrust" and the associated concepts?
2. What conceptual arguments do the teachers construct when confronted with experimental data? The concept of upthrust was selected for this study for the following reasons: (a) it encapsulates several familiar Physics-associated concepts (sub-concepts) related to upthrust, such as pressure, pressure difference, weight, force, buoyancy, Archimedes' principle, etc; (b) there is significant research documenting learners' misconceptions related to the sub-concepts (Clement, 1982; Slotta et al., 1995; Trumper, 1999; Loverude et al., 2003; Ramma et al., 2014; and (c) learners usually encounter difficulties in understanding upthrust and Archimedes' principle (Loverude et al., 2003; Struganova, 2005; Zhang et al., 2003).

Sample characteristics

All of the participants in this study, constituting a purposive sample ($N = 23$), had obtained a bachelor's degree in Physics and had enrolled on a two-year professional development course called the Post Graduate Certificate in Education (PGCE) course in Physics at the local teacher training institute. Currently, the participants teach Physics in secondary schools in Mauritius. The participants' teaching experiences ranged from 3 months to 15 years at the time of the study. Table 1 displays some descriptive background information on the teachers' teaching experiences. To preserve the anonymity of the participants, the teachers' names were replaced with codes T1 - T23.

The 23 teachers work across 21 secondary schools in Mauritius, which amounts to about 12% of the secondary school population.

Data collection tools

The data collection tool comprised a task-based worksheet and a video-based focused group interview. The worksheet (see Appendix A) was administered before and after the experiment. They consisted of the same task on the concept of upthrust, which involved predicting the approximate value of force registered on a spring balance when a 10 N load, hooked to a spring balance, is lowered in a beaker containing water. Initially, participants were tasked with predicting the

Table 1. Teachers' years of experience.

Range of teaching experience	Number of teachers (%)	Identifier
Less than 1 year	10 (43.5%)	T2; T4; T6; T8; T10; T11; T12; T14; T21; T23
More than 1 year, but less than 5 years	10 (43.5%)	T1; T3; T5; T7; T9; T13; T15; T17; T20; T22
More than 5 years	3 (13.0%)	T18; T16; T19

spring balance readings at various load positions in the water and providing scientific justifications. Subsequently, they were asked to replicate this process while conducting an experiment and providing the actual spring balance values and corresponding justifications.

Data collection process

Data were collected in three phases using the Predict-Observe-Explain model (White & Gunstone, 1992). During Phase 1, teachers were allocated 25 minutes to complete the task, emphasising generating comprehensive justifications for their responses. Following the collection of these worksheets, teachers progressed to Phase 2, where they received a fresh worksheet with the same task and were supplied with various instruments, including a spring balance, a beaker of water, a retort stand, and slotted masses.

The teachers were allotted 30 minutes to complete the second task, with a five-minute allowance for apparatus set-up and 25 minutes for task completion. During both phases, participants were required to work individually. Implementing two phases in quick succession was intended to facilitate participants' connection with and reflection on the explanations they provided during the prediction activity in Phase 1 and encourage them to re-evaluate their interpretations in light of the experimental results in Phase 2.

In Phase 3, a focus group interview was conducted using video-based technology, involving eight out of the 23 participants. These teachers were selected because they willingly consented to participate in the 56-minute interview session.

Ethical consideration

All teachers were assured that their identities would remain confidential. Those who willingly agreed to participate in the video-based interview were provided with a clear understanding of the interview's purpose and were guaranteed that the recording would be deleted once data analysis was concluded. Additionally, teachers were informed of their option to withdraw from the study at any point during the three phases. Remarkably, all participants remained active after becoming involved in the study. For Phase 3, only the eight previously consented teachers actively participated in the video-based focus group interview.

Item constructs

The assessment worksheets were designed to evaluate teachers' comprehension of "upthrust" and its associated concepts. These items were categorised into distinct sections to gauge factual, conceptual, and procedural knowledge (see Appendix B).

Face validity

Two senior Physics professors in academia have reviewed the worksheets and concluded that the tasks, questions, and evaluation criteria are indeed valid for assessing the content knowledge of Physics teachers regarding upthrust.

Reliability and validity

We employed Rasch measurement to ascertain the construct validity of our instrument, which gauges factual, conceptual, and procedural knowledge. In our assessment of the instrument's reliability and validity through the lens of the Rasch model, we utilised the following benchmarks (see Table 2):

Data analysis process

Instrument validation

After conducting our initial analysis using the Rasch model, we found that the item's reliability was 0.80. This value aligns with the acceptable range established by previous studies (Bond & Fox, 2007; Fisher, 2007). Nevertheless, we also noted a negative point measure correlation coefficient (PTMEA CORR) for the Archimedes1 item. This observation implies a discordance between the item's response and the underlying construct, as Linacre (Lincare, 2007) pointed out. Upon exclusion of the item from the Rasch analysis, the subsequent item statistics unveiled that all remaining items displayed a positive point-measure correlation coefficient (PTMEA CORR), signifying a robust association between the item responses and the underlying construct under examination. The reliability value, standing at 0.81, and the separation measure, at 2.07, both fell within the acceptable range. The separation measure indicates that teachers competencies in factual knowledge can be categorised as either low or high.

After our initial analysis, the conceptual knowledge items showed a moderate level of reliability, with an item reliability measure of 0.47 and an item separation of 0.94. However, we observed that two items, specifically "Archimedes1" and "Pressure2", had a negative point measure correlation coefficient of –0.08. As a result, we decided to exclude these items from the analysis. This exclusion led to a slight enhancement in the instrument's reliability measure, which increased to 0.58, and an improvement in item separation, which rose to 1.17. However, during the polarity diagnosis, it became evident that four items, namely "Archimedes2", "Tension2", "Weight2", and

Table 2. Reliability and validity.

Rasch model statistics	Benchmark	Reference
Item reliability	>0.8	Bond and Fox (2007)
Item separation	≥2.0	Lincare (2007)
PTMEA CORR	>0	Bond and Fox (2007)
INFIT MNSQ	0.5 – 1.5	Bond and Fox (2007)
OUTFIT MNSQ	0.5 – 1.5	Bond and Fox (2007)
INFIT ZSTD	– 1.9 – 1.9	Bond and Fox (2007)
OUTFIT ZSTD	– 1.9 – 1.9	Bond and Fox (2007)

“Density2”, surpassed the fit criteria. This suggests that they might not be assessing the same underlying construct as the remaining items in the instrument. It may be necessary to revise or eliminate these items to uphold the validity and reliability of the instrument when measuring conceptual knowledge within the intended population.

Following removing these four items, a third instrument was created, demonstrating a reliability coefficient of 0.66 and a separation measure of 1.33. As per Fisher (2007), the reliability value can be deemed satisfactory, while the instrument’s validity is supported by positive point-measure correlation coefficients (PTMEA CORR) spanning from 0.15 to 0.77. For the analysis of procedural knowledge, specifically logical and analytical skills, we adopted a similar approach. However, we only considered results after the experimentation because more than 90% of the teachers (21 out of 23) provided little to no evidence of procedural knowledge before the experimentation.

During the initial analysis using the Rasch model, we removed the logical item “*The object’s weight remains constant since mass is a constant quantity and g is not changing*” from the instrument. This item had a negative PTMEA CORR value (−0.11) and was identified by only one teacher with a low ability measure of −2.59. In the subsequent analysis, we deleted analytical item A1, “*When fully immersed, the object displaces the same amount of water at whatever depth it is situated*” as it did not meet the fitting criteria of the Rasch model. Although no negative correlation between points and measures was observed on the third run, the instrument’s reliability was deemed very low, with an item reliability measure of 0.47, which falls below the acceptable threshold (Bond & Fox, 2007; Fisher, 2007). As a result, no Rasch analysis was conducted for the procedural knowledge case. Nevertheless, we utilised triangulation of this aspect alongside the interview results.

To analyse the items, facts, or concepts correctly identified before and after the experimentation, we considered the following classification, similar to a confusion matrix, as shown in Table 3.

It is essential to underscore that a false positive result indicates a type 1 error. In this context, it implies that a teacher erroneously dismissed a correct concept post-experiment despite correctly identifying it before the experiment. We gauge this by reporting the false discovery rate (FDR), which denotes the expected proportion of type 1 errors and its counterpart, precision or positive predictive value (PPV), about factual and conceptual knowledge about upthrust.

In our case, PPV signifies the proportion of teachers who maintained affirmative responses after the experiment, having initially correctly identified the relevant concepts.

The FDR and the PPV are computed as follows:

Table 3. Description of codes.

Classification	Analysis code	Description (with code)
True Positive	11	Identification of concept before (1) and after experiment (1)
True Negative	00	No identification of concept before (0) and after experiment (0)
False Positive	10	Identification of concept before (1) experiment but not after (0)
False Negative	10	No identification of concept before (0) the experiment but after (0)

$$FDR = \frac{False\,Positive}{True\,Positive + Fales\,Positive}$$
$$PPV = \frac{True\,Positive}{True\,Positive + Fales\,Positive}$$

Qualitative data analysis

Thematic analysis was the chosen qualitative descriptive method for analysing the textual data derived from interview transcripts and uncovering themes through systematic coding. Peer debriefing was utilised to bolster the credibility and trustworthiness of our analysis. This process involved cross-checking the findings and interpretations against the original raw data. In this collaborative effort, two authors actively engaged in the thematic analysis, while the remaining two offered an external review and perspective.

Results

Analysis of factual knowledge

The radar chart (Figure 3) illustrates a positive correlation between the teachers' factual knowledge before and after the experimentation. However, a noticeable trend emerged: Teachers tended to revise their initially correct responses after the experiment, leading to a less knowledgeable disposition in the subsequent phase. This regression is evident in reducing the area covered by the "Response 1 After" items compared to the "Response 1 Before" items.

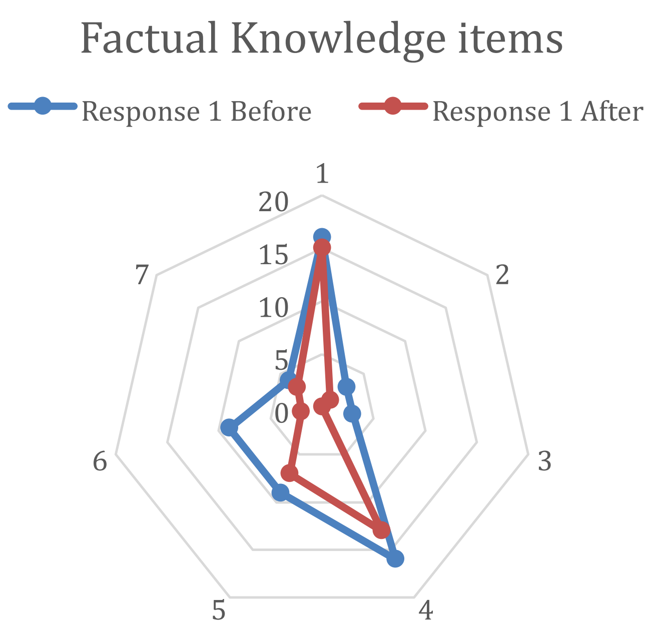


Figure 3. Factual knowledge.

Classification of responses

Table 4 categorises the responses based on true positives, false positives, false negatives, and true negatives. The false discovery rate (FDR) was found to be 100% for the items "Archimedes" and "Tension", indicating that all teachers who initially answered correctly changed their responses to incorrect ones post-experimentation. These findings suggest a significant challenge in teachers' ability to maintain factual accuracy under experimental conditions.

Rasch Model Analysis

The Person-Item map (Figure 4) further highlights the difficulties faced by teachers. Only six out of 23 teachers (T1, T9, T10, T12, T15, and T18) performed above the mean item measure, indicating a general struggle with factual knowledge. Even the highestperforming teachers had difficulty referencing critical items such as Archimedes' principle, tension, pressure, and density. This suggests that substantial gaps could impede effective teaching even among those with relatively more robust content knowledge.

However, at the lower end of the spectrum, seven teachers had measures ranging from −2.2 to −1.3, below the measure of the most accessible items, "Upthrust1" and "Weight1" (measure = −1.07). This observation reveals a significant concern regarding the content knowledge of these seven teachers. In the context of the Rasch model analysis, a lower measure indicates a higher difficulty level for the participant in correctly answering the item. The items "Upthrust1" and "Weight1" were considered the most accessible, or easiest, items within the set, with a measure of −1.07. These items were expected to be well within the grasp of all participants, given that they represent fundamental Physics concepts that inservice teachers should understand well. However, the fact that these seven teachers had measures ranging between −2.2 and −1.3, lower than the measure for these most accessible items, suggests that they struggled significantly even with basic, foundational Physics concepts. This difficulty indicates a need for more profound content knowledge and potential gaps in their basic understanding of the Physics principles crucial for effective teaching.

Analysis of conceptual knowledge

The radar chart in Figure 5 reveals a more pronounced reduction in the area covered by "Response 1 After" items compared to "Response 1 Before" items, indicating a significant drop in teachers' ability to identify conceptual knowledge after experimentation correctly.

Table 4. Responses related to factual knowledge before and after experimentation.

Item	True Positive	False Positive	False Negative	True Negative	FDR	PPV
Upthrust	13	3	2	5	0.1875	0.8125
Archimedes	0	3	1	19	1	0
Tension	0	3	0	20	1	0
Weight	10	6	3	4	0.375	0.625
Force	5	4	2	12	0.444444	0.555556
Pressure	2	7	0	14	0.777778	0.222222
Density	1	3	2	17	0.75	0.25

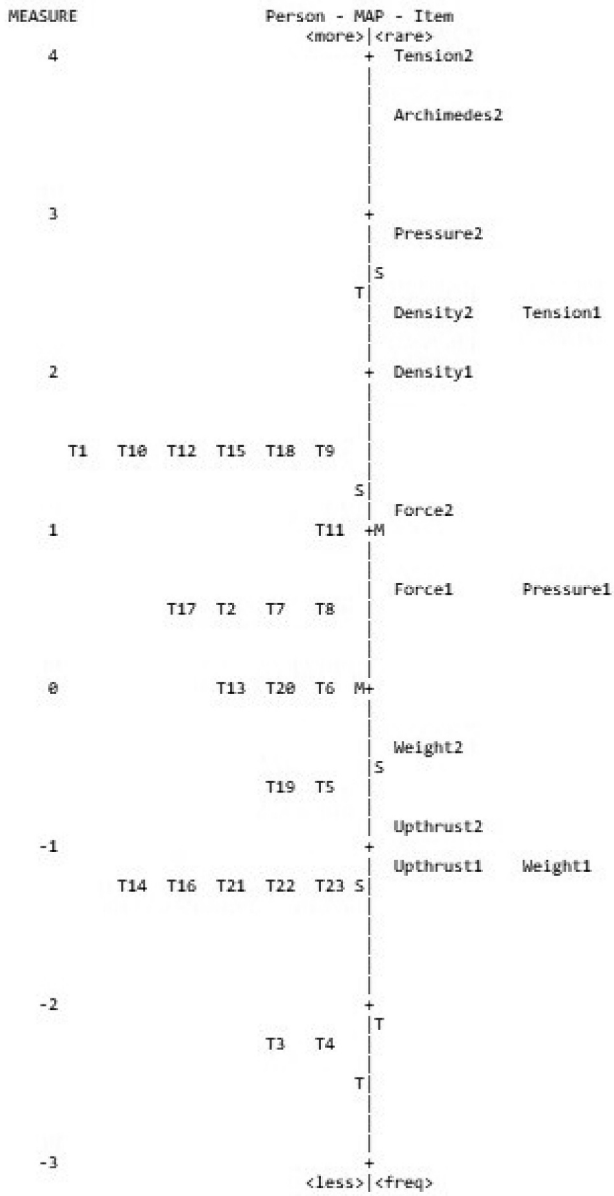


Figure 4. Person and item measures of factual knowledge indicate items before and after experimentation.

Classification of responses

As shown in Table 5, a large proportion of teachers provided correct responses before the experiment but failed to maintain these responses afterwards. This pattern suggests that the experimental phase may have introduced confusion or highlighted gaps in their conceptual understanding that were not evident during the prediction phase.

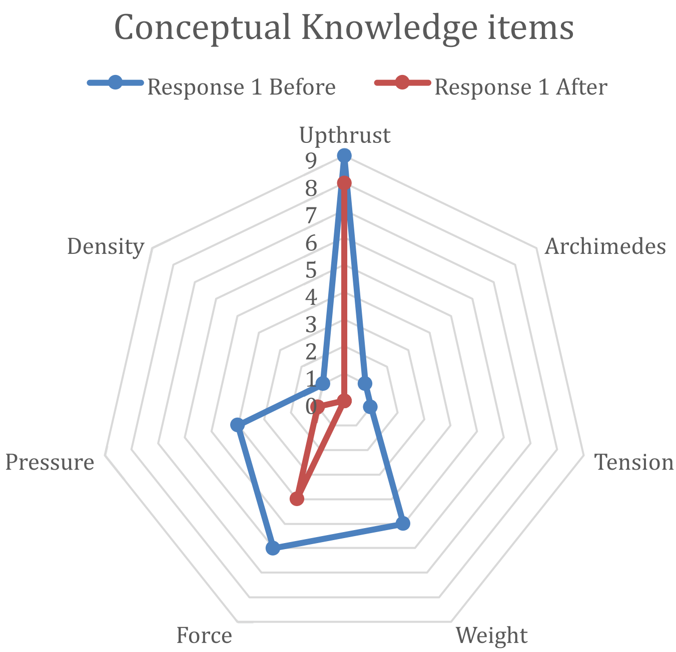


Figure 5. Conceptual knowledge.

Table 5. Responses related to conceptual knowledge after and before experimentation.

Item	True Positive	False Positive	False Negative	True Negative	FDR	PPV
Upthrust	6	3	2	12	0.33	0.67
Archimedes	0	1	0	22	1	0
Tension	0	1	0	22	1	0
Weight	0	5	0	18	1	0
Force	0	6	4	13	1	0
Pressure	0	4	1	18	1	0
Density	0	1	0	22	1	0

Rasch Model Analysis

The Person-Item map (Figure 6) shows that 14 out of 23 teachers have person measures ranging from −2.4 to −0.1, suggesting that the majority of the teachers were operating at a lower ability level, where they could only comfortably handle the most accessible item, "Upthrust1", which had an item measure of −0.24. This indicates a severe limitation in their ability to engage with more complex or challenging concepts. Two items had measures around 3.45, significantly higher than the highest person measure of 2.85, indicating that these items were challenging. Even the most capable teacher (T10) found these items challenging, as their ability measure was within the difficulty of these items. This disparity highlights a significant gap between the teachers' current knowledge and the expected understanding of these concepts.

In Figure 7, the radar chart reveals critical insights into the teachers' understanding of the relationship between upthrust and tension. Specifically, the participants' most

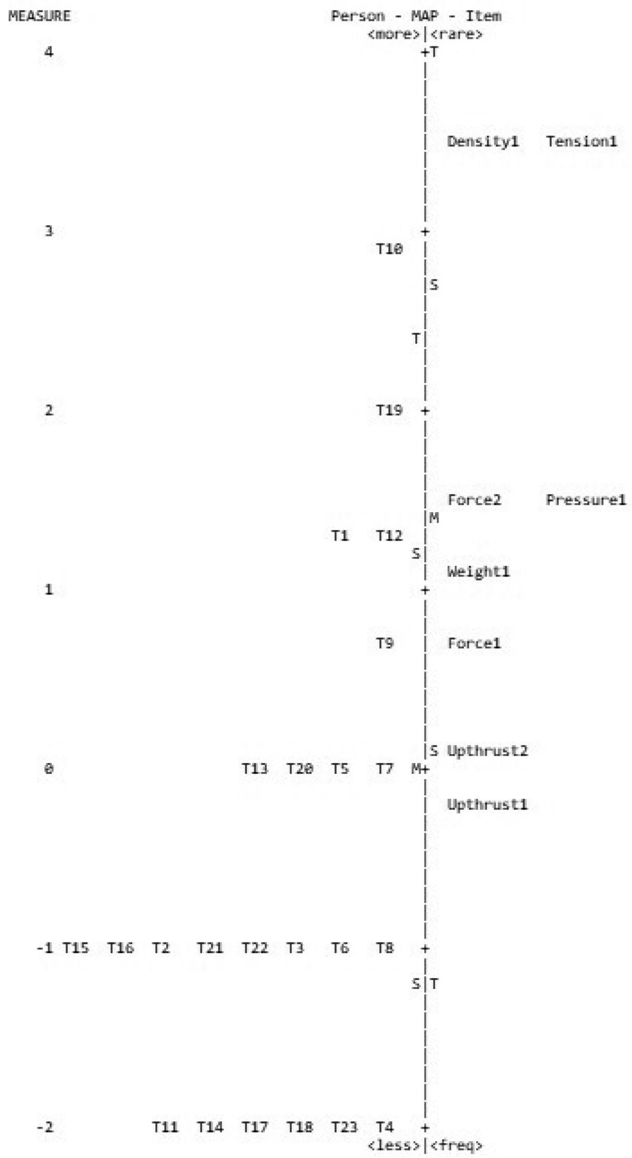


Figure 6. Person and item measures related to conceptual knowledge analysis of procedural knowledge.

frequently identified correct item was the logical item L4, which posits that tension (T1) should decrease when the load is partially immersed due to the upward force of upthrust (U1). However, only 8 out of the 23 teachers accurately articulated this concept in their responses.

This finding is significant because it highlights a widespread difficulty among teachers in connecting theoretical knowledge with practical observations. Although the spring balance readings demonstrated a reduction in tension as the load was partially submerged, 15 teachers – representing the majority – failed to explain this phenomenon

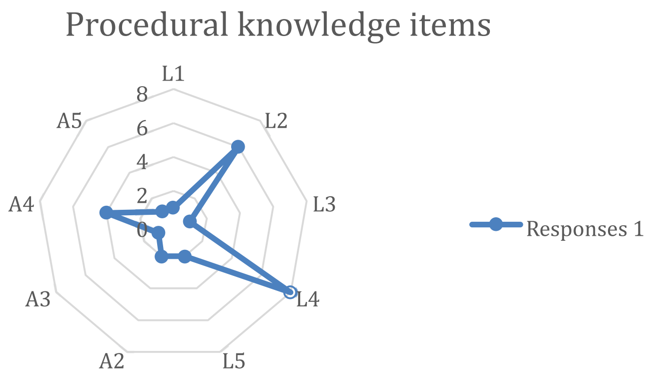


Figure 7. Procedural knowledge.

correctly. Moreover, this result reflects a potential over-reliance on rote memorisation of formulas rather than properly comprehending the underlying Physics. The fact that only a minority could correctly link the observed data to the principle of upthrust implies that many teachers may not fully grasp how buoyant forces influence tension in practical scenarios. This gap in understanding could have significant implications for their teaching practices, as they may struggle to convey these concepts effectively to students.

Rasch Model Analysis

According to the Rasch model (Figure 8), 14 teachers had person measures −4.18 to −2.72, well below the mean item measure of −2.56, indicating a significant challenge in demonstrating procedural knowledge. Only one teacher, T12, performed above the mean item measure, emphasising teachers' general difficulty in this area.

Effect of teaching experience

Using the three-person item maps as our foundation, we analysed how teaching experience influences teacher expertise across three distinct knowledge domains. Since all the measurements are standardised on a uniform scale, we divided the analysis into two distinct parts:

(1) The first part examines the relationship between teaching experience and measures at or above the mean item measure (0).
(2) The second part focuses on measures below the mean item measure (0).

This approach allows us to differentiate between teachers who perform at or above the expected level and those who fall below it. It provides a more nuanced understanding of how teaching experience correlates with expertise in each domain, as shown in Table 6.

Table 6 presents the association between teaching experience and knowledge of upthrust. Interestingly, participants with less than one year of teaching experience

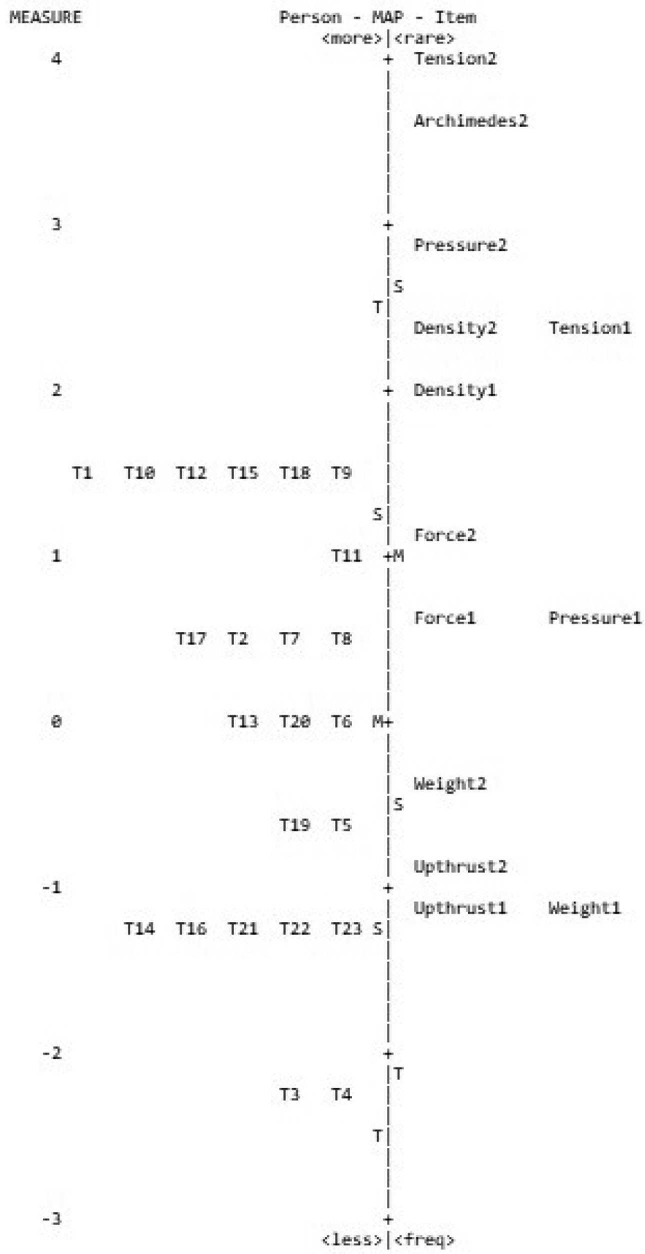


Figure 8. Person and item measures on procedural knowledge.

performed relatively better across all knowledge domains than those with more experience. This counterintuitive finding suggests that more experienced teachers may be more set in their ways, potentially limiting their adaptability to new pedagogical approaches or concepts.

Table 6. Association of teaching experience and knowledge of upthrust.

Teaching experience	Factual knowledge		Conceptual knowledge		Procedural knowledge	
	Below item mean	Above or equal to item mean	Below item mean	Above or equal to item mean	Below item mean	Above or equal to item mean
Less than 1 year	7	3	9	1	9	1
More than 1 year but less than 5 years	8	2	10	0	10	0
More than 5 years	1	2	2	1	3	0
Total	23		23		23	

Predicting weight from a spring balance

Figure 9 illustrates an example of an acceptable response to the spring-balance problem provided to the participants during the "Observe" stage of the Predict, Observe, Explain (POE) model. This problem is integral to understanding how the forces of upthrust and gravity interact when an object is submerged in a fluid.

In this scenario, the key assumption is that the load eventually comes into contact with the base of the container, resulting in a reading of 0 N on the spring balance at point D.

A representative theoretical response can be depicted graphically, as illustrated in Figure 10. According to Archimedes' principle, once an object is fully submerged, the upthrust force remains constant because the weight of the displaced water – which equals the upthrust – remains unchanged. This constant upthrust is a product of the volume of water displaced, the density of the water, and the gravitational acceleration, all of which are fixed parameters when the object is fully immersed. Thus, regardless of how deep the object is submerged beyond the point of total immersion, the upthrust does not increase further, and the weight measured by the spring balance decreases correspondingly until it reaches zero when the object is in contact with the base.

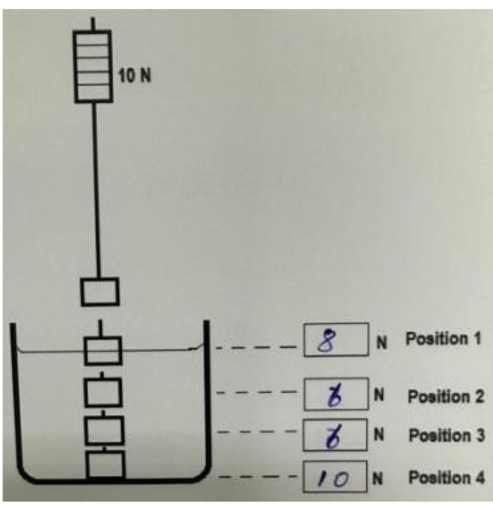


Figure 9. An acceptable answer to the spring-balance problem.

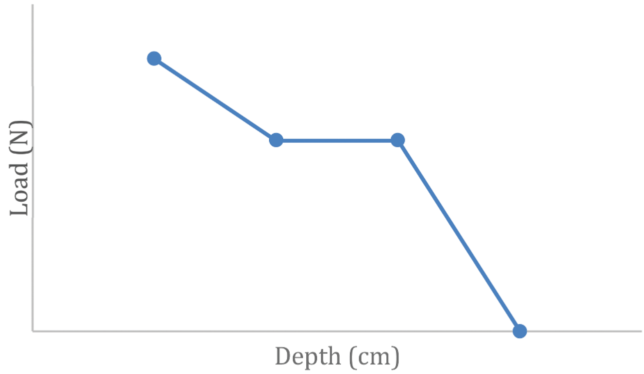
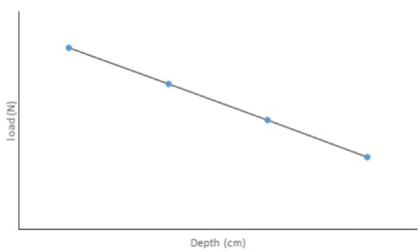


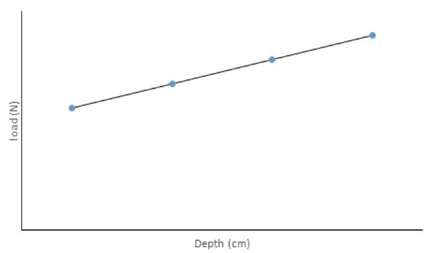
Figure 10. Load-depth relationship of the spring-balance problem.

However, only one teacher (T5) predicted values that corresponded with the theoretical representation of the variation of the weight of the load on the spring balance (see Figure 8). As for the other teachers, all of them made faulty predictions. The frequent faulty predictions are depicted graphically below (Figure 11 (a) – (c)).

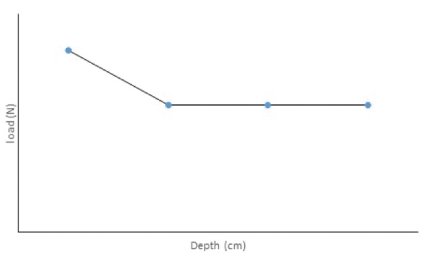
The responses from the remaining six teachers needed to be more consistent than the anticipated answers. Notably, two teachers responded (5, 0, 0, 0), while another teacher responded with (0, 12, 14, 16), and yet another with (5, 5, 0, 0). These coordinates correspond to the values assigned to options A, B, C, and D in the given order.



(a) Six teachers



(b) Five teachers



(c) Five teachers

Figure 11. Incorrect responses to the spring-balance problem.

Findings from the group interview

The thematic analysis of the interview data produced three main themes: upthrust task, learning of Physics, teaching of Physics, and professional development.

Upthrust task

All eight teacher participants unanimously concurred that the hands-on activity significantly improved their comprehension of the situational problem. Nevertheless, they acknowledged that they had committed errors in their prior assessments and could not substantiate their observations from the activity with valid justifications. Furthermore, they admitted that, in certain instances, they had rescinded their initial accurate statements before the experiment due to their limited grasp of the underlying theory.

Teacher 8: *I have realised the importance of doing the experiment … even teachers could make mistakes.*

One of the participating teachers was astonished at the errors he had not anticipated.

Teacher 5: *I was pretty astonished that the answers were not correct, and even the theory, I did not grasp well.*

It is worth noting that most teachers explicitly mentioned that they did not rely on their “common” or “layman” knowledge, such as assuming that the upthrust at positions B and C are equal. Instead, they preferred to adopt a theoretical perspective to reach their conclusions. Nevertheless, their efforts were largely unsuccessful.

Teacher 4: *I think, as a Physics teacher, our first focus is to relate it to some theory … perhaps, a teacher from another subject area would have related it to their practical experience.*

Learning Physics

All the teachers who participated in the study indicated that during their undergraduate studies, they primarily received lecture notes that emphasised the resolution of drill and practice-type questions. On certain/specific occasions, they were supplemented with PowerPoint presentations and practical exercises. While there were some interactions between lecturers and students, participants expressed a desire for more opportunities to seek clarification through questions. The practical sessions needed to be directly aligned with the theoretical concepts covered in previous theory classes. Due to the separation of theory and practical sessions in terms of timing, the concepts often remained abstract and disconnected.

Teacher 5: *I prefer parallel teaching; let's say some notes on some concepts, and if we can do some hands-on activities [on the related concepts], I think it would have been much better.*

Teacher 3: *In some cases, even in the practical classes, we were given notes rather than discussing the practical sessions.*

It is worth noting that, in a limited number of cases, videos were utilised for demonstrations, and international speakers were brought in as guest presenters. These practices were primarily driven by the individual initiatives of particular lecturers rather than firmly established institutional procedures. Similarly, it came to light that lecturers actively promoted critical thinking and encouraged research on the subject in certain instances. However, it was observed that this approach led to numerous cases of unsuccessful outcomes. Furthermore, one teacher highlighted that "*my lecturers learned their notes by heart and kept writing and could not be interrupted*". Consequently, this approach led to examination papers that largely mirrored those from previous years. The remaining teachers concurred with the prevailing trend of lecturers primarily focusing on teaching to the test.

Teacher 6: *Even if we have not learned a concept, we can get an A on the exam … we learn to pass our exam … after one month, we forget everything.*

At the secondary level, the participants observed that the predominant teaching methods included the traditional "chalk-and-talk" approach and teaching geared towards standardised testing. They also remarked that there needed to be more opportunities to connect theoretical concepts with practical applications or real-life scenarios. Instead, there was a notable focus on repetitive practice and drill exercises.

Teaching Physics

The teacher participants indicated that they emulate the "expert" methods employed by their secondary school instructors and undergraduate lecturers in their classrooms. Additionally, they observed that school administrators and authorities prioritise high pass rates, creating a sense of obligation to cover the entire curriculum and adequately prepare their students for upcoming examinations. These sentiments are succinctly captured in the following statement:

Teacher 9: *We have to meet management's expectations; give them 80% – 90% pass. But, when we analyse the situation, what do the students understand? What have they learned? It's just what we teachers have told them. They know it through books and notes, but have they grasped the concept? Have they learned Science as it should be?*

Although they all acknowledge the significance of incorporating ICT into their Physics teaching, its integration in the classroom remains predominantly confined to using PowerPoint presentations to enhance teacher-led explanations. Nevertheless, after participating in pedagogical training at the institute, the teachers have reported notable enhancements in various teaching practices. These improvements include an increased capacity to conduct hands-on demonstrations, offer visual aids, implement formative assessments with feedback, evaluate students' prior knowledge, analyse examiners' reports to identify learning difficulties and incorporate peer presentations as motivational strategies.

Professional development

The teachers unanimously emphasised that professional development courses should offer suitable pedagogical strategies for teaching Physics concepts and serve as a platform for revisiting and challenging previously acquired knowledge. Furthermore, aligning with syllabus modifications, these courses should furnish them with the necessary knowledge, comprehension, and skills to effectively teach newly introduced concepts, especially since they may have graduated from university some time ago.

Teacher 1: *It would have been helpful* [if the PGCE emphasises content in conjunction with pedagogy]

Teacher 6: *There is a new syllabus now . . . , and we don't have adequate notes to guide our thinking and teach confidently.*

When reflecting on their university experience, all eight participants indicated that their decision to enrol in a Physics degree programme stemmed from their ambition to become Physics teachers. As a result, they expressed the belief that their undergraduate education would have significantly benefited from including elective courses focused on classroom management and teaching practices.

Discussion

The findings from this study provide significant insights into the challenges in-service Physics teachers face in understanding and applying fundamental concepts related to upthrust. The analysis using radar charts, the Rasch model, and teachers' responses revealed considerable gaps in their factual, conceptual, and procedural knowledge, which have important implications for teacher education and student outcomes.

Challenges in factual and conceptual knowledge

The radar charts and Rasch model analyses demonstrate that most teachers struggled with factual and conceptual knowledge. For instance, the radar charts showed a reduction in correct responses after the experimentation phase, particularly in conceptual knowledge. This decline suggests that while some teachers may initially identify correct concepts, they need help to retain or apply this knowledge when faced with experimental tasks. The Rasch model further supports this finding, highlighting that only a small subset of teachers performed above the mean item measure, with most teachers finding even the least challenging items difficult.

These results indicate that many teachers possess only a superficial understanding of fundamental Physics concepts, which needs to be improved for effective teaching. This superficiality is problematic because teachers with weak content knowledge are less likely to provide accurate explanations or address student misconceptions, ultimately impacting the quality of Physics Education.

Procedural knowledge deficiencies

The analysis of procedural knowledge revealed even more concerning results. Most teachers needed help to make correct predictions or provide valid justifications for their observations during the experiment. For example, only one teacher (T5) predicted values that corresponded with the theoretical expectations regarding the weight variation on the spring balance. The fact that the other teachers made faulty predictions, often with significant inconsistencies, highlights a need for a deeper understanding of the principles governing the behaviour of objects in fluid environments.

This inability to accurately predict and explain outcomes suggests that many teachers need more procedural knowledge to guide students through scientific reasoning and experimentation. Such knowledge is critical for fostering inquiry-based learning, where students are encouraged to explore and understand the scientific principles underlying physical phenomena.

Impact of teaching experience

Our analysis of teaching experience relative to the person-item measures revealed some surprising trends. Teachers with less than one year of experience performed relatively better than those with more experience, particularly in factual and conceptual domains. This suggests that more experienced teachers rely more on outdated methods or are less open to new pedagogical approaches. Alternatively, it might reflect a lack of ongoing professional development that challenges experienced teachers to revisit and update their content knowledge.

This finding emphasises the importance of continuous professional development focused on pedagogical strategies and deepening content knowledge. Novice and experienced teachers need opportunities to use up-to-date scientific concepts and methods to ensure their instruction remains relevant and practical.

Implications for professional development and curriculum design

The findings from this study highlight the urgent need for targeted professional development programmes that address the specific weaknesses identified in teachers' knowledge. These programmes should strengthen content and procedural knowledge, emphasising the connection between theoretical concepts and practical applications. Professional development should also encourage reflective practices, where teachers critically evaluate their understanding and teaching methods in light of new learning.

Additionally, the curriculum for teacher training programmes should be reviewed to ensure that it adequately prepares teachers for the complexities of teaching Physics.

This includes integrating more hands-on, inquiry-based learning experiences that mirror teachers' challenges in the classroom.

Teachers' challenges in making accurate predictions and providing relevant justifications for their predictions and observed phenomena aligned with similar difficulties documented in student experiences, as reported by Allen (2014). Specifically, teachers often predominantly predicted that the depth of the water was the primary determinant of the upthrust force. In most instances, separate load values at points B and C were recorded.

Interestingly, the formation of the teachers' mental models (Jasdilla et al., 2019) regarding upthrust can be traced back to their educational backgrounds, encompassing their experiences in secondary school and university. On the one hand, participants readily acknowledged that they did not encounter the concept of upthrust in school or university in a manner that connected the theory they learned to the data acquired during hands-on sessions. On the other hand, despite firmly believing in the importance of theoretical aspects in Physics, most participants failed to demonstrate sufficient procedural knowledge of upthrust. This discrepancy underscores the need to move beyond a didactic, teacher-centred teaching model that heavily relies on algorithms. Instead, it calls for a more balanced approach incorporating structured hands-on activities and theoretical instruction to foster conceptual understanding (Crouch et al., 2004).

There is a need for a shift in teachers' mental models and beliefs, which can be catalysed through continuous professional development courses. These courses should not assume that graduate teachers have mastered their content knowledge. While these programmes provide essential pedagogical considerations, the training institute should also ensure that misconceptions are addressed and teachers' beliefs are challenged. In the early stages of cognitive development, secondary schools should actively promote conducive learning environments for acquiring scientific inquiry skills and a growth mindset. This can be achieved through regular experimental classes. The hands-on activities conducted in these experimental classes should consistently reinforce theoretical knowledge, including factual, conceptual, and procedural aspects, through university courses. The POE (PredictObserve-Explain) model is a valuable tool for supporting the scientific journey of learners (Kearney et al., 2001) and aspiring teachers.

Conclusion

The study revealed that the content knowledge of in-service Physics teachers is contingent upon their prior experiences, both theoretical and experimental, acquired during their secondary school and university education. Inaccuracies and gaps in their knowledge impede their pedagogical content knowledge, which is scrutinised during professional development courses.

In this study, the Predict-Observe-Explain (POE) model was effectively employed to investigate the content knowledge of 23 in-service Physics teachers on the concept of Upthrust. Specifically, the model assisted in determining that these teachers possessed a reasonable grasp of certain concepts associated with Upthrust, such as weight and force. However, their ability to connect these concepts with related ones, such as Archimedes' Principle and tension, was inadequate.

The teachers' factual and conceptual knowledge deficiency significantly impacted their procedural knowledge. They struggled to make w(van der Zanden, et al.)ellinformed predictions during the Upthrust task and, more critically, encountered difficulties providing valid justifications and argumentation when faced with conflicting predicted and observed values.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Notes on contributors

Yashwantrao Ramma is a Professor and Deputy Director General (Academic) at Université des Mascareignes, Mauritius. He has led research projects and published on teachers' content and pedagogical content knowledge in physics, critical thinking in teaching and learning, indiscipline and school violence in primary schools, students' transitions from secondary to university, and teacher training.

Ajeevsing Bholoa is an associate professor of mathematics education at the Mauritius Institute of Education, Mauritius. His research interests are related to integrating technology as a pedagogical tool in teaching and learning mathematics and identifying content knowledge and pedagogical content knowledge of mathematics teachers.

Mike Watts is a Professor of Education at Brunel University, London, UK. He has conducted significant studies in both formal and informal educational settings in the UK and abroad and has published widely on teaching and learning through books, journal articles and numerous conference papers.

ORCID

Yashwantrao Ramma http://orcid.org/0000-0003-4967-2572

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Appendices

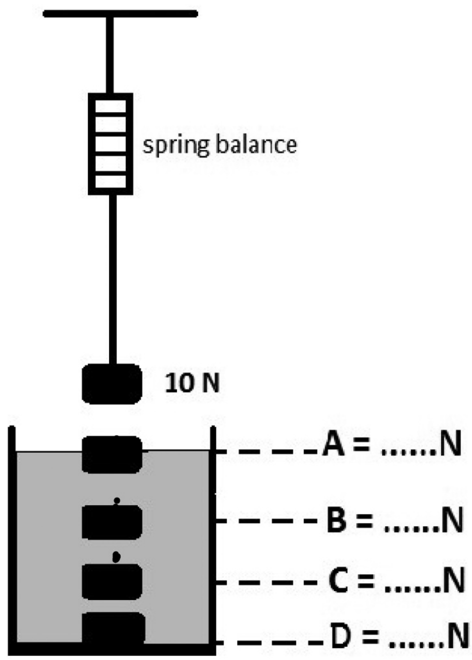
Appendix A

The figure below shows the different positions A-D of an object suspended to a spring balance as it is slowly lowered in a beaker of water.

When the object is above the water, the spring balance shows 10 N

(i) Based on your logical thinking, write down the values (approximately) registered by the spring balance when the object is situated at the various positions, represented by letters A, B, C and D.
(ii) Explain your reasoning carefully (and comprehensively) in the space provided.

(1) Value at position A: … … … … … … … … … … … … … … Reason:
(2) Value at position B: … … … … … … … … … … … … … … … Reason:
(3) Value at position C: … … … … … … … … … … … … … … Reason:
(4) Value at position D: … … … … … … … … … … … … … … Reason:



Appendix B

Concept	Factual Knowledge	Conceptual Knowledge	Procedural Knowledge		
			Logical	*Analytical*	*Drawing conclusion*
Upthrust or Buoyant force	Use of the concept in the context of the set problem.	The existence of an upward force in the liquid arising as a result of pressure difference x area. This force is predetermined by the weight of the displaced water.	Once the object is completely immersed, the upthrust ($U_2 > U_1$), remains same anywhere in the water since weight of displaced water remains unchanged. It should be noted that in the case of the submerged load, it is the volume of the load that influences the magnitude of the upthrust. Once the object makes contact with the bottom of the vessel, the tension in the string decreases; however the upthrust does not change.	When fully immersed, the object displaces the same amount of water at whatever depth it is situated. The weight of water displaced = volume of water displaced (constant) x density of water (constant) x acceleration of free fall (constant). All the three quantities do not change when the object is fully immersed.	The conclusion refers to the readings given for the different positions of the load. ● <10 N ● < [A] ● = [B]
Archimedes' principle	For e.g. if "Tension" is mentioned, it should be related to the spring balance	Relationship with buoyant force should be made explicit and reference should be made to the weight of displaced water. Upthrust is equal to the weight of the displaced water.			
Tension		Reference should be made to the reading on the spring balance being the result of the tension in the spring.	The value shown on the spring balance is the result of the tension (T_0) in the string.	Applying Newton's third law, the weight is the "action" while the tension is the "reaction" which is registered by the spring balance.	
Weight		Discussion should revolved around the fact that the weight of the block in the liquid is constant. However, the spring balance registers the apparent weight of the block in the liquid.	The weight of the object remains constant since mass is a constant quantity and g is not changing. However, care should be taken not to confuse with "apparent weight".	W = m x g; since mass (m) is a constant quantity and that acceleration of free fall (g) does not change, weight remains constant. It is the apparent weight that changes. At equilibrium, upward force = downward force. Therefore, T + U = W; *T* = W – U. Thus, due to the presence of upthrust, the resultant force (Tension $T_1 < T_0$) decreases.	

(*Continued*)

(Continued).

Concept	Factual Knowledge	Conceptual Knowledge	Procedural Knowledge		
			Logical	*Analytical*	*Drawing conclusion*
Resultant force	or if "Pressure" is used, it should be related to water and not to the load or the spring balance, etc.	The tension in the string originates from a resultant force between weight and upthrust.	Newton's 2nd law applies. The force is a resultant one. Knowledge of Newton's 3rd law as prior knowledge.	When the object just makes contact with the bottom of the vessel, the following forces act on the object, Tension ($T_{\uparrow}$), Upthrust ($U_{\uparrow}$), Normal Reaction ($N_{\uparrow}$), Weight ($W_{\downarrow}$). $T + N + U = W$; $T = W - (N + U)$ When the object makes firm contact with the bottom of the vessel and the string becomes slack, $T = 0$ and therefore, $W = (N + U)$. Thus, $0 \leq T < T_1$	$0 \leq [D] \leq [C]$ (For this part, since no information has been given as to whether the load makes contact with the base, a variety of answers will be accepted based on teachers' thinking)
Pressure		Pressure is exerted on any object when immersed in it as a result of water molecules hitting the object. Pressure exerted by a liquid, water in this case, is: $p = h \times \rho \times g$	There should be a decrease in the tension (T_1) when the load is partially immersed given that upthrust (U_1) acts in the upwards direction.	$\Delta P = (h_2 - h_1)\,\rho\, g$ Once the object is fully immersed, the pressure difference remains same anywhere in the liquid since the object is rigid, its width does not change. Density and acceleration due to gravity do not change.	
Pressure difference		In this case, upthrust results from the pressure difference (lower and upper side of the object) x area			
Density		The density of air and water being different leads to the apparent weight. Density plays a crucial role in Archimedes principle.	The liquid is incompressible.		