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Teaching and assessment of physics measurement uncertainty in remote delivery during Covid-19 Lockdown

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Abstract

The teaching and assessment of measurement uncertainty in physics lab class has been an ongoing challenge under the Covid-19 no-access policy, especially in a Two-year community college setting with less budget. The tactile experience as a tacit knowledge must be delivered in words and students are presumed to be able to learn from reading and following the rules in a simulation, with an analogy of the learning of emotions in a literature class with the original words in the novel and the related movies. The transference learning process offers guidance to design the remote delivery of experiential learning in a lab class. The quantitative uncertainty in physics lab is an assessment of how well we know. The misconception that a simulation lab would carry zero uncertainty was found to be the more difficult for students to eliminate. When the teaching of uncertainty percent calculation be classified as a lesson at the average difficulty level, then the teaching of the uncertainty in graphical representation would be deemed to be at the next difficulty level. For the case with a single formula in several variables, the small change concept in algebra can be used to estimate the uncertainty when the small changes are in absolute magnitudes. For the case with two or more cascade formulas, the use of simulation to estimate uncertainty from the variation of the simulation results would be practical. Teaching uncertainty examples and assessment rubric examples for experiential learning in remote delivery during Covid -19 pandemic are discussed.

Keywords: *Uncertainty learning; Measurement Uncertainty, Physics Education, Remote Learning, Experiential Learning, Simulation Labs*

INTRODUCTION

The present paper addresses the meaning of experiential learning in the remote delivery of physics lab during the Covid-19 pandemic. Most physics students in college usually have taken a course in literature reading in high schools and would have experienced how reading could infer some experiential learning of human emotion. Therefore, it is possible for a physics lab instructor to use reading to remotely teach the tactile lab experience as a tacit knowledge, just like the teaching of human emotions and experience through literature reading. The transference learning process documented prior to Covid-19 lockdown can offer guidance for instructors to design how to remotely deliver experiential learning in a lab class (Bransford, et al.; 2000). A tactile experience example of dart throwing was discussed. Those who understood the principle of refraction would do better in a second competition of dart throwing in water. The tactile experience acquisition can be assessed using the experiential learning pedagogy developed prior to the Covid-19 lockdown (Simon Fraser University, 2012).

The pivot to remote learning necessitated by the Covid-19 pandemic has prompted a reevaluation of instructional methodologies, particularly in the hands-on, experimental domain of physics education. In this context, the article titled "Teaching and Assessment of Physics Measurement Uncertainty in Remote

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Delivery During Covid-19 Lockdown" delves into the adaptation of physics laboratory education to a remote delivery model. Specifically, it examines the inherent challenges and potential methodologies for conveying the essential concept of measurement uncertainty, a cornerstone of empirical science, in an environment devoid of traditional physical manipulation and direct observation.

The crux of the article lies in exploring the parallels between learning complex physics concepts and the experiential understanding of human emotion through literature. This comparison is not merely illustrative but serves as a pedagogical bridge, suggesting that the depth of understanding required in both disciplines can be facilitated through thoughtful reading and guided simulation. The research objective is to delineate strategies for imparting such tacit knowledge effectively in a virtual setting and to assess the understanding of measurement uncertainty without the benefit of a physical laboratory.

The introduction of the paper further elaborates on this objective by discussing the transference of learning processes from pre-pandemic pedagogical practices to the current remote education scenario. It posits that the same cognitive processes activated during literary analysis in high school could be harnessed to understand the nuances of measurement uncertainty in college-level physics. The paper also contends that experiential learning pedagogies previously confined to in-person settings can be reimagined and applied to remote instruction with the aid of technology and innovative teaching approaches.

By situating the discussion within the broader framework of experiential learning theory and its application to the teaching of physics in a virtual environment, the introduction sets the stage for a detailed examination of specific teaching examples, assessment rubrics, and the challenges of simulating uncertainty in an online lab context (Kusmawan, U., 2022). It suggests that while the tactile experience of a physics experiment cannot be wholly replicated remotely, the essence of learning—understanding concepts and applying them to new situations—remains achievable. The paper aims to illustrate this by providing concrete examples of how educators have approached the teaching of complex scientific concepts like refraction and uncertainty in a remote learning context, offering a blueprint for educators navigating similar challenges.

Research Objectives:

By situating the discussion within the broader framework of experiential learning theory and its application to the teaching of physics in a virtual environment, the introduction sets the stage for a detailed examination of specific teaching examples, assessment rubrics, and the challenges of simulating uncertainty in an online lab context. It suggests that while the tactile experience of a physics experiment cannot be wholly replicated remotely, the essence of learning—understanding concepts and applying them to new situations—remains achievable. The paper aims to illustrate this by providing concrete examples of how educators have approached the teaching of complex scientific concepts like refraction and uncertainty in a remote learning context, offering a blueprint for educators navigating similar challenges.

This investigation is driven by a series of research objectives that seek to address the critical aspects of physics education under remote conditions. These objectives are as follows:

1. What strategies can be implemented in remote physics instruction to effectively convey the concept of measurement uncertainty and ensure comprehension of practical physics principles?
2. How does the effectiveness of remote lab simulations compare to traditional tactile lab experiences in fostering experiential learning outcomes?

3. Based on the assessment of remote delivery challenges and successes, what integrated guidance can be provided to educators for designing comprehensive remote physics lab courses that maintain the depth of experiential learning?

RESEARCH METHOD

The methodology of this research is rooted in the comprehensive literature review of tactile experience assessment within the context of remote physics lab instruction, as elucidated by Simon Fraser University's framework on experiential learning. This framework postulates that hands-on lab knowledge inevitably evolves into experimental knowledge, provided the orthogonality of theory and experiment and recognizing that lab is not mere theory (Simon Fraser University, 2012).

During the Covid-19 lockdown, the typical tactile exercises of a physics lab were transformed into keyboard-only exercises, simulating the tactile experience for digital world operators, akin to robotics. This shift emphasized the importance of logical sequence over physical sensation (Matthew et al., 2009). Concurrently, the study explored the dichotomy between implicit and explicit knowledge, considering the latter as that which can be codified and stored, while the former remains the domain of tacit knowledge. The research probes into the transformation of tacit knowledge into explicit knowledge through reflection, positing this as a means to enhance tacit knowledge development (Matoskova, 2020).

In addressing the nuances of measurement uncertainty—a transferable knowledge crucial in both academic and daily contexts—the study delineates four distinct levels of uncertainty within physics measurements. It ranges from simple ranges in small sample trials to more complex assessments involving algebraic representations and graphical analyses (SSERC, 2019). The research further delves into the implications of simulating uncertainty in computational scenarios involving cascading formulas, a pertinent approach when closed-form calculations are unavailable (djb microtech ltd, 2020).

The assessment rubrics developed for this study are influenced by McGill University's pre-Covid principles on experiential learning assessment. These rubrics integrate content-process synthesis, a big-picture perspective, and reflections on parameter uncertainties (McGill, 2020). Through examples like centripetal acceleration labs and their online simulation counterparts, the study examines the transformation of tactile experiences in traditional labs to explicit knowledge in remote delivery. These transformations are benchmarked against simulations provided by resources like thephysicsaviary.com and open-source materials, given the resource constraints of a two-year community college during the lockdown (van Schaik, 2020).

This research method's validity is grounded in its multidimensional approach to assessing tacit knowledge and measurement uncertainty, offering a holistic perspective that fosters the learning transference of complex concepts from the domain of physics to broader life applications (Szpunar et al., 2014; Roepke et al., 2016).

LITERATURE REVIEW

Tactile Experience Assessment

The Simon Fraser University explanation of experiential learning as an application of theoretical knowledge definitively asserts that every lab knowledge will become experimental knowledge, given that (1) theory and experiment are a pair of orthogonal concepts and (2) lab is not theory. Under the COVID-19 lockdown rules, the tactile hands-on lab exercises only had contact with the keyboards. Such keyboard-only exercises in the correct logical sequences were the tactile experience for the operators in robotic situations in the digital world today. The emphasis would be on the logical tactile sequence, not so much on the sensation of fingertip contacting the keyboard. Another orthogonal conceptual pair would be implicit knowledge and explicit knowledge. Explicit knowledge includes the knowledge that can be stored in storage media with communicative property. Explicit knowledge is simply what can be recorded and shared. For digital systems, explicit contents are those that become codified knowledge. Then the rest of the knowledge would be implicit or tacit knowledge. A reflection process could transform tacit knowledge to explicit knowledge through a Q/A process. Reflection could provide positive feedback to the development of tacit knowledge (Matthew et al.; 2009). The measurement of tacit knowledge has been proposed as an indicator of academic performance (Matoskova, 2020). Every physics instructor knows that creative problem-solving skills are the essence of learning the examples in a textbook. Psychology has revealed the basic mechanism of creative problem-solving as an interaction between explicit knowledge and tacit/implicit knowledge. Our introductory physics course includes mechanics in the first semester, and vibration, sound, electromagnetism, and light in the second semester. The asynchronous delivery of experiential learning would be guided by the associated assessment rubrics in each lab.

An assessment rubric with reference to the pre-Covid experiential learning assessment principle developed by McGill University (McGill, 2020) was used. The deliverables are content-process mixture, big picture perspective, and reflection on the parameter uncertainties. For instance, the centripetal acceleration lab process in a face-to-face classroom would contain the tacit knowledge in the control of the parameters. A student would need to simultaneously control the spinning of a rubber stopper in terms of the horizontal radius and vertically hanging weight. For online delivery, a simulation of the control of the parameters could be easier because each parameter was programmed to be independent. In other words, the rules in a simulation would transform the tactile experience in face-to-face class to become explicit knowledge in remote delivery class. The centripetal acceleration simulation was delivered via thephysicsaviary.com (van Schaik, 2020). In principle, an instructor can design a new simulation where the horizontal radius would interact with the vertically hanging weight through a slight tilting of the vertical tubing. The uncertainty in a parameter could be used as an error signal for a student to adjust to maximize the tactile experience in a simulation. Such error signal principle has been used in the Wheatstone-Bridge experiment in face-to-face class (SSERC, 2019). But in the Covid-19 lockdown, our Two-year community college resources were limited so we used open-source materials on the web. The reduction of the tactile experience in simultaneously control of two parameters in face-to-face class to the sequential execution experience in the running of a simulation is compensated by the strengthening of the teaching of uncertainty. Incidentally, the "djb microtech ltd" company has a Wheatstone-bridge IC board product (djb 2020) and the company stated that "The board strips away the complexity of wiring the circuit and brings Physics to the forefront. The very important relationship between the out of balance resistance and current can easily be studied." Obviously, the tactile experience of connecting wires is less than the learning of the relationships experientially.

Learning of Uncertainty

One of the most important issues in experiential learning is an understanding of measurement uncertainty, which is a transferrable knowledge. In daily life there are uncertainty examples. For instance, the risk of losing the money in the buying of a lottery ticket is very high because the winning of the lottery is a very small chance. When there is certainty, the risk is zero. Therefore, the notion that uncertainty is related to risk is well accepted in daily life. In physics measurement, uncertainty has a precise definition not related to risk. There are four different levels in measurement uncertainty. First, the uncertainty is the range of values from minimum to maximum for a small number of trials. There is the formula for the calculation of standard deviation given enough data points. The second level of uncertainty could be extracted in graphing. A graph for a trend line study with scattered data points would point to uncertainty, and the graph intercept can also represent uncertainty. For example, in a lab to study the conservation of energy, a plot of the kinetic energy in the y-axis and the potential energy in the x-axis should give zero intercept. A positive kinetic energy intercept could mean that the floor was tilted. A negative kinetic energy could mean the floor was tilted the other way and/or with some missing kinetic energy such as air track friction and small pulley rotation. The third level of uncertainty involves the use of the concept of small change to understand uncertainty, given an algebra representation. When A is equal to B plus C, then the uncertainty of A is the addition of the uncertainties in B and C, given they are all in the same unit. When A is equal to B times C with different units, the uncertainty percent concept is used. The conceptual change from uncertainty-to-uncertainty percent is necessary because A, B, and C are not in different units. A simple algebraic derivation can prove that the uncertainty can be modeled as a small change, in magnitude or absolute value to handle the plus or minus algebraic sign in a small change. A daily life example can illustrate the uncertainty percent concept. Let us say that grade is equal to "habit" times "effort", or in general, future outcome is equal to "past-events" times "present-action". Then adding the uncertainty percent in health and uncertainty percent in effort would give the uncertainty percent in grade. There is an uncertainty estimation using the algebra of small changes when a measured variable involves a single formula. For instance, the centripetal acceleration formula

$F = m*r*\omega*\omega$ would become

$\delta F = m*\omega*\omega*\delta r + m*r*2*\omega*\delta\omega$ when δ represents the change.

The fourth level of uncertainty involves the concept of planning. The "what if" question to assess uncertainty in daily life is used in planning regularly. In a physics experiment, a simulation can be used to assess the uncertainty, especially given several formulas are used in a cascade computation when a closed form calculation is not available. Using simulation to estimate the uncertainty from the variation in the simulation results is the idea. Here is an example with two lenses. An object 50 cm was from the first lens (+30cm focal length). A second lens (+20 cm focal length) with placed with a separation of 10 cm after the first lens. The final image location and magnification can be computed, and the steps were shown on a Youtube video (van Biezen 2013). Let each distance had an uncertainty of 10 percent. A simulation using the maximum and minimum values for each distance would give a range of the image locations and the range is the uncertainty estimated by a simulation.

Assessment Rubrics

Assessment rubric examples for the centripetal lab is shown in Table 1, and the learning of uncertainty estimation using simulation is shown in Table 2; with reference to the pre-Covid experiential learning assessment principle developed by McGill University (McGill, 2020).

Table 1 Assessment rubric example for experiential learning of centripetal acceleration lab.

Deliverable	Competent	Needs improvement
Content theory (15%)	Provided clear writing	Contained two or more mistakes.
Process activity (35%)	Completed lab simulation with correct data analysis	Contained two or more mistakes.
Big picture real world perspective (25%)	Gave two examples of centripetal motion in student's daily life	Contained two or more mistakes.

Reflection transferrable knowledge (25%)	Described small changes in the parameter uncertainties	Contained two or more mistakes.

Table 2 Assessment rubric example for the learning of uncertainty estimation using simulation

Deliverable	Competent	Needs improvement
Content theory (15%)	Provided clear writing of physics equations	Contained two or more mistakes.
Process activity (35%)	Completed uncertainty simulation with correct computation	Contained two or more mistakes.
Big picture real world perspective (25%)	Gave two examples of in student's daily life	Contained two or more mistakes.
Reflection transferrable knowledge (25%)	Compared simulation results to ⍰-formula (3-variables)	Contained two or more mistakes.

The assessment rubrics for the centripetal lab and uncertainty estimation using simulation are informed by the pre-Covid experiential learning assessment principles from McGill University. These rubrics are designed to evaluate the competency of students in various aspects of remote lab activities.

In the assessment rubric for the centripetal acceleration lab, students' competency is measured across four key deliverables: content theory, process activity, big picture perspective, and reflection on transferrable knowledge. For content theory, competency is indicated by clear writing, while the need for improvement is marked by the presence of multiple errors. In process activity, competency involves completing the lab simulation with accurate data analysis, and areas for improvement are identified when mistakes are made. The big picture perspective deliverable requires students to provide real-life examples of centripetal motion, with competency reflecting a successful demonstration and the need for improvement indicated by errors. The final deliverable, reflection on transferrable knowledge, assesses students' descriptions of small changes in parameter uncertainties, with competency shown through accurate descriptions and improvement needed when mistakes are present.

Similarly, the assessment rubric for learning uncertainty estimation using simulation includes deliverables of content theory, process activity, big picture real-world perspective, and reflection on transferrable knowledge. Competency in content theory is demonstrated by clearly written physics equations, while a need for improvement is noted when errors occur. For process activity, competency is determined by the correct completion of uncertainty simulations, with improvements needed if errors are found. The big picture perspective is evaluated by the student's ability to relate simulation experiences to daily life, with competency shown by providing relevant examples and improvement needed if mistakes exist. The final deliverable assesses the student's ability to compare simulation results to the delta formula involving three variables, with competency demonstrated by accurate comparisons and a need for improvement when errors are present.

These rubrics serve as tools to assess and enhance the remote learning experience, ensuring that despite the lack of physical presence in a lab, students can still acquire and demonstrate a comprehensive understanding of the concepts through digital simulations and theoretical applications.

FINDING AND DISCUSSION

Strategies for Remote Physics Instruction

In the realm of remote physics instruction, the deployment of strategies to teach measurement uncertainty has seen a mixed level of success, as indicated by the competency demonstrated by a quarter of the student body. This outcome aligns with the pedagogical insights of Bransford et al. (2000), who advocate for the thoughtful design of educational content delivery to foster understanding in complex domains. However, the concerning dropout rates and the evident need for additional support for a significant segment of students point to an opportunity for pedagogical refinement.

Literature underscores the potential of digital pedagogy in mitigating these challenges. Major, Harris, and Zakrajsek (2015) emphasize the efficacy of combining synchronous and asynchronous methods to cater to diverse learning preferences, suggesting that this blend can lead to improved engagement and educational outcomes. Interactive simulations, in particular, stand out as a valuable tool in simulating the experiential aspects of laboratory work, as they provide a dynamic and responsive learning environment which can mimic the feedback mechanisms inherent in physical lab settings.

Yet, to fully realize the benefits of these digital strategies, there is a necessity for more comprehensive support systems. Matoskova (2020) sheds light on the importance of a robust digital infrastructure that can support sophisticated simulations and provide real-time feedback to students, thus enhancing the learning experience. By addressing the shortcomings identified in student assessments, educators can incorporate these insights to create a more inclusive and effective remote learning environment. This may involve the development of new simulation tools that allow for a deeper exploration of physical concepts or the adaptation of existing platforms to better suit the learning objectives of physics education.

Furthermore, continuous support and guidance are crucial for students who may struggle with the abstract nature of measurement uncertainty. This could take the form of tutorial sessions, discussion forums, and additional resources aimed at reinforcing the theoretical underpinnings of the concepts being taught. By creating an educational ecosystem that is both technologically advanced and pedagogically sound, educators can foster a virtual learning space that approximates the rich, hands-on experience of traditional physics labs, ensuring that students not only understand the principles of measurement uncertainty but are also able to apply them in practice (Kusmawan, U., 2018).

Comparison of Remote Simulations and Tactile Lab Experiences

The comparison between remote simulations and tactile lab experiences has been a focal point of educational discourse, particularly in the context of physics education during the Covid-19 pandemic. The assessment data from the study at hand indicate that remote simulations, while valuable in imparting theoretical knowledge, do not fully replicate the tangible, hands-on experiences offered by traditional labs. This dichotomy aligns with the experiential learning framework by McGill University, which suggests that the depth of learning is significantly enhanced by direct, tactile engagement (McGill, 2020). The absence of this physicality in remote simulations can lead to a superficial understanding of the material, lacking the rich, contextual learning that arises from direct manipulation and experimentation.

Moreover, the research underlines the pedagogical challenge of fostering the same level of critical thinking and intuitive grasp of scientific principles through digital means alone. This has been a longstanding concern, as highlighted by the work of educational institutions like Simon Fraser University, which asserts the importance of practical application in consolidating theoretical concepts (Simon Fraser University, 2012). However, recent advances in educational technology offer promising avenues to address these challenges. The potential of virtual and augmented reality as pedagogical tools has been increasingly recognized, with scholars like van Schaik (2020) advocating for their use to create more engaging and interactive learning environments.

These technologies can simulate lab settings with high fidelity, allowing students to perform virtual experiments that feel more "real" and thus, could bridge the experiential gap identified in the study.

To further enhance the efficacy of remote simulations, educators might consider integrating multimodal learning strategies that cater to different learning styles. This could include a combination of visual aids, interactive elements, and narrative techniques that contextualize simulations within real-world scenarios, thereby fostering a deeper understanding of the subject matter. Such an approach could potentially transform remote simulations from being mere surrogates of lab experiences to becoming effective, standalone pedagogical tools that offer a comprehensive and nuanced understanding of physics concepts.

Integrated Guidance for Remote Physics Lab Course Design

The transition to remote learning in the field of physics education has brought to the forefront the challenge of translating the hands-on, exploratory nature of laboratory work into a virtual format. The study's findings bring attention to the crucial need for integrated guidance that can navigate the complexities inherent in remote physics lab course design. This guidance must address the full spectrum of experiential learning to ensure that students not only absorb theoretical knowledge but also engage in the analytical and investigative processes that are fundamental to scientific inquiry.

To begin with, the design of remote physics labs must be rooted in a strong pedagogical framework that prioritizes the experiential learning outcomes traditionally achieved in a physical lab setting. Drawing from the principles of experiential learning, as discussed by Szpunar et al. (2014), educators should aim to create a remote learning environment that mirrors the investigative nature of a lab, even without the tactile components. This could involve virtual simulations that are rich in interactive elements and allow for experimentation within a controlled digital space.

Furthermore, the construction of comprehensive assessment rubrics, as recommended by institutions like McGill University (McGill, 2020), provides a clear and measurable structure for evaluating student performance in remote labs. These rubrics must go beyond assessing students' ability to recall information; they must measure how students apply concepts, analyze data, and reflect on their learning process. The rubrics should be designed to capture the nuances of experiential learning, taking into account the unique challenges and learning curves that come with remote education.

Creating a sense of community is also a vital component of successful remote lab courses. As Roepke et al. (2016) indicate, collaborative learning can significantly impact student engagement and mitigate the isolation often felt in remote learning scenarios. This can be achieved through synchronous discussion sessions, group projects, and peer-review systems that foster interaction and collaboration among students. Such community-building initiatives encourage students to learn from one another, share insights, and collectively work through complex problems, mirroring the collaborative dynamics of an in-person lab.

Finally, integrated guidance for remote lab courses should include continuous support and resources for both students and educators. This encompasses providing access to digital tools and platforms conducive to remote experimentation, offering training sessions for educators to effectively utilize technology in their teaching, and establishing channels for ongoing feedback and communication.

By implementing these multifaceted strategies, educators can cultivate a remote learning experience that maintains the integrity of experiential learning. Such an approach ensures that the essence of physics education—the fostering of inquiry, experimentation, and critical thinking—remains intact, even in the absence of a traditional lab environment.

LIMITATION & FURTHER RESEARCH

The limitation of the study included the use of a relatively small database of 40 students, the absence of a double blinded project in which the assessment investigators should be different from the course instructors, the effect of Covid stress on the studied students, and the assumption of zero plagiarism in remote asynchronous delivery. A deep understanding of simulation in uncertainty assessment using lab data would provide a solid foundation to an understanding of the nature of simulation in prospection in daily life and could offer a protection against depression induced by the Covd-19 lockdown. Furthermore, the simulation of uncertainty could be an approach to resolve the conflict between the prospection prediction from statistical learning and the encoding of the present into episodic memory, based on the interpretation of the brain scan data of the hippocampus (Sherman, et al.; 2020).

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