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COMPARING SMARTPHONES TO TRADITIONAL LAB EQUIPMENT IN A HIGH SCHOOL PHYSICS EXPERIMENT

MA Thesis

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ABSTRACT

As smartphones become more prevalent in everyday life, educators are faced with the decision of whether to utilize these tools in their classrooms. This investigation focused on using a smartphone as an investigative tool and measuring the impact on student interest, curiosity, and digital multitasking while completing a physics lab. An additional investigation examined whether students preferred the smartphone or the traditional tool for measuring sound and analyzed the reasons for their choices. It was found that using a smartphone as a scientific instrument can positively impact student curiosity in science topics, but also that students do not perceive smart devices to be as valuable as traditional devices and tend to prefer the latter when conducting physical measurements.

Keywords: Smartphone, interest, curiosity, digital multitasking, science classroom, tool preference

TABLE OF CONTENTS

APPENDIX

INTRODUCTION

A secondary science classroom in 2022 looks quite different from one 10 years prior. Textbooks might still be present in some classrooms, but due to funding and other constraints, many have been replaced with digitally sourced materials, flexbooks, and online learning platforms, all of which are highly adaptable to fit the evolving needs of individual teachers and classrooms (Hill, 2022). In a classroom laboratory you may also see traditional lab tools such as hotplates, beakers, and Bunsen burners. Over time, however, much of this equipment has broken down, and unfortunately funding may not have been made available to replace these tools. To address this need, teachers have turned to other creative options, such as virtual reality and online simulations (Jones, 2017). With both applications, students have the chance to practice and manipulate real science concepts, in a safe and low-risk environment. Often used in place of lab materials that are not available or to simulate conditions that are not possible to replicate in a classroom, these tools can help bring innovative ideas into the classroom that lay beyond the potential of traditional science labs. Access to online instruments became particularly vital to science teachers in the early days of the pandemic; in 2020 science educators were suddenly faced with the need to deliver materials online, without the possibility for in-person science labs. If teachers did not actively work to facilitate the opportunities to explore scientific concepts in a laboratory setting, students would be deprived of the chance to develop the many competencies that are only possible through hands-on manipulation and discovery. Virtual tools like PHET, an online interactive simulation database founded in 2002 by Nobel Prize winner Carl Wieman, were suddenly in higher demand than ever before (Rose, 2022). In the case of PHET, these 150+ simulations are free, translated into around 90 different languages, and can be accessed digitally on something as simple as a smartphone – an ideal foil to the challenges science educators faced in the spring of 2020.

Access to portable devices has also drastically changed in the last decade. Computer labs do still exist in many schools, but the availability of compact and convenient options, for example laptops and tablets, has changed how many students are able to access resources in the classroom. Additionally, many students in wealthier countries possess a small computer that can fit in easily their pockets – while it is not guaranteed that every student will have one, smartphones have become ubiquitous in the classroom.

Despite existing since 1992 (The Smartphone Turns 25…, 2017) smartphones continue to be a polarizing subject in modern society, particularly in the classroom. In general, smartphones have been demonstrated to hinder learning by creating opportunities for distraction (Junco, 2012; Junco & Cotten, 2012; Levine et al., 2012); many teachers, schools, and countries have worked to ban phones altogether in the classroom (Strauss, 2018). Despite these bans occurring in schools around the world, there is still debate as to whether blanket prohibitions are the wisest course of action. Valerie Strauss (2018) of the Washington Post argues:

> Blanket bans are rarely the most effective ways to fix human behavioral problems. Today's children were born in a world where technology and digital gadgets were already a normal part of life. From an educational perspective, banning smartphones in schools would be an easy solution but not necessarily the smartest one. Instead, we should teach children to live safe, responsible, and healthful lives with and without their smartphones and other mobile devices. Education can be a powerful tool to teach children to exercise self-control and to live better lives.

More recently, educators and researchers have been exploring if there is an academic benefit to applying smartphones as tools in the classroom (Hochburg et al, 2018; Kaps et al, 2021; Kuhn & Vogt, 2017; Vieyra et al, 2015). Public education funding continues to range widely depending on location, and for many schools it simply has not been an option to bring computers, whether desktop, laptop, or tablet, into each individual classroom. Given these constraints, it makes practical sense to consider that smartphones could be a solution in the face of decreasing public education funding (Graham, 2022). Additionally, smartphones have sensors that have become increasingly complex, with the ability to investigate and observe light**,** gravitational acceleration, basic mechanics, and other integral scientific concepts. Therefore, it seems critical that educators and researchers continue to explore how these tools could impact learning and the overall student experience in science classrooms.

LITERATURE REVIEW

As we examine the usefulness of smartphones in the classrooms, it could be important to first identify how these tools are perceived by teachers and students. Teacher opinion about smartphone use in the classroom runs the full gamut. In the years following the first iPhone release in 2007, many schools, administrators, and teachers moved to ban smartphones from the classroom (Lenhart et al., 2020). These bans were based on concerns about student distraction, but also influenced by lack of teacher training and understanding of the technology (Thomas et al., 2014). Some research has suggested that outright bans support academic achievement; banning smartphones in classrooms has been linked to an improvement in academic scores (Beland & Murphy, 2016). Smartphone distraction seems to occur more readily with students who struggle academically; banning these devices in the classroom can have the most positive academic impact for this group of students, which can consequently lead to a reduction in academic inequality in schools.

A study by O'Bannon and Thomas (2014) illustrated that age is a significant factor influencing the perceived value of smartphone use in the classroom. The research highlighted those teachers over the age of 50 years of age who were less likely to possess a personal device, were less enthusiastic about smartphone use in class and perceived these devices to be less valuable as classroom tools. Additionally, teachers in this age group perceive the impediments associated with smartphone use to a greater degree; there was a higher level of concern about cheating, cyberbullying, class disruption, academic impacts on writing ability, sexting, the availability of inappropriate internet content, and overall access to a smartphone. Eight years later, we can assume that more teachers over the age of fifty will possess and use a smartphone in their everyday life, though teacher age may continue to be a leading factor when it comes to the willingness to use a smartphone as a tool in the classroom.

It seems that even before Bannon and Thomas' investigation in 2014 that teacher perceptions had already began to change to be more inclusive of the use of smartphones in the classroom (Thomas et al., 2013). These changing attitudes seem to stem from two causes: Teachers finding more practical utility for smartphones supporting their own professional work, as well as attributing increased use of technology in the classroom to lead to increased student engagement and motivation. When planning to use these devices in the classroom, teachers need to be aware that not all students would have guaranteed access to their own smartphone, and planning is required to accommodate those who do not possess one. One solution is to allow students to work collaboratively and share a smartphone as needed; however, schools could also address this issue directly by maintaining a set of smartphones available for student use (Thomas et al., 2013). Smartphones are now considered to be a professional necessity and for many citizens smartphones are their primary link to the online world (Smith, 2020). These devices can be used to access health information, navigate personal finances, search for a home, seek employment and support from government services, and access educational content. Given the importance that digital literacy now plays in everyday life, it is reasonable to consider that schools could support learning how to safely navigate this ever-changing technology. Integrating smartphone use into the learning process by demonstrating its practical uses in a science classroom could be an authentic means to prepare students for the decisions they will make as an adult.

Despite more than a decade of concerns about smart devices in the classroom, smartphones are used daily by many school-age children (Hochberg et al., 2018). These smart devices computers have the potential to be beneficial during scientific exploration, with the additional benefit that students are already familiar with the tool itself, as well as many of its potential functions. But how do students perceive the usefulness of this everyday instrument? To start, young people have been capable of recognizing the potential utility of these devices for some time. In a study by Tossell et al. (2014), students who had never previously owned a smartphone were given one to use freely for a year. Prior to receiving the phone, the students indicated they believed the smartphone could positively impact their learning experience – both from an academic and an administrative standpoint. However, after one year, the consensus shifted and students felt their smartphones were a source of distraction, and negatively impacted their educational success. So even when the users themselves perceive the tool to have potential usefulness, it can also be acknowledged that diversions can occur very easily.

THEORETICAL FRAMEWORK

Several factors are at play in determining if smartphones can and should be used as nimble and efficient scientific tools. This study will lean on three primary theories of learning: Multitasking Theory, Cognitive Load Theory, and Context-Based Learning. Each of these theories will play an integral role in examining if a smartphone is a useful instrument – or simply a distraction – in the classroom.

Multitasking Theory

When assessing the value of using smart devices in the classroom, one factor to consider is the students’ competence in using a smartphone effectively. Digital multitasking is a major concern when it comes to applying these devices in a learning setting: Teachers are concerned that students will participate in non-academic online activities during class time, and that this may negatively impact their academic success. Multitasking is traditionally defined as completing more than one task simultaneously, and digital multitasking infers that this behaviour will incorporate a digital or smart device. Multitasking theory is strongly rooted in the examination of task switching, a phenomenon observed by Rogers and Monsell in their 1995 paper. This research focused on the task-switching costs that occur when a person switches between relevant and irrelevant tasks. Not surprisingly, there is a cost attributed to task switching, suggesting that multitasking behaviour itself is not more efficient than focusing on one task at a time. More recent research suggests that multitasking with online media can lead to poor academic outcomes (Alghamdi, et al., 2020). In general, students are not as good at multitasking as they perceive themselves to be. A study by Bowman et al. (2010) investigating multitasking behaviour in students found that students took notably longer to accomplish an academic task while simultaneously instant messaging. So, while students believe they may be working more efficiently by participating in multitasking behaviours, they are switching back and forth between tasks, and thus taking more time to complete the academic work.

To better understand multitasking as a phenomenon, it seems relevant to ask why students may be participating in multitasking behaviours during class time. There is evidence to suggest that digital multitasking behaviours are driven by sensation-seeking impulses, and those students with high sensation needs tend to demonstrate stronger media multitasking behaviours (Chang, 2016). So, students may be participating in these behaviours because of a personal need that is not being met in a classroom environment. If we wish to curb negative behaviours in the class, then it would be practical to further examine these needs and motivations, to better address the issues that arise due to smartphone use.

Context-based Learning

Despite the concerns about digital multitasking, there is a school of thought examining whether smartphones could be used to positively enhance the learning experience. Smartphone applications allow students to observe the physical universe in ways that the classroom does not allow, through interactive maps, virtual reality, simulations, and even 3-D astronomical projections. Smartphones also have the capability to perform many practical tasks in the classroom due to their many sensors: acceleration, sound/sound pressure, frequency, time, lux (light intensity), magnetic flux density, and ionizing radiation (Kuhn and Müller, 2018).

Introductory mechanics are typically taught in high school physics, a topic where smartphones could potentially come in handy, due to one simple part: Most smartphones contain a small silicon chip call an “accelerometer”. This small component responds to flipping and rotating, prompting the screen to automatically flip to the correct orientation, allowing the user to view the screen more comfortably. But the functionality of this small chip also allows users to measure some basic mechanical movements, namely velocity, linear acceleration, gravitational acceleration, and centripetal force (Vieyra et al., 2015). Students often struggle conceptually with these topics and Vieyra et al. make the argument that teachers should be seeking “more engaging instructional strategies” to address this challenge, beyond the typical lecture-and-lab formula.

The practical advantages of smartphones as tools of measurement go beyond the array of sensors available: The ubiquity of these devices make them available for use for students outside of the classroom. By asking students to use a familiar tool, students can pursue explorations outside of the classroom, facilitating the connection of their learning to the real world. This falls in line with a push towards more Context-Based Learning (CBL) in the science classroom. CBL theory suggests that young learners require real-life, complicated problems to become more effective problem solvers. Problems encountered in the adult world are rarely straight-forward or well-structured, and therefore young learners should have exposure to more complex problems in addition to the cut-and-dry problems that are typically taught in the safe confines of a classroom (Johnson et al., 2011).

In a more science-specific environment, Context-Based Science Education (CBSE) encourages the use of “realistic contexts as starting point and anchor for learning science, thereby giving significance and meaning to the science-content as well as offering students to become engaged in scientific thinking and practice” (Prins et al., 2018). This means connecting students to authentic and accessible problems, with the hope of increasing students’ interest, curiosity, and motivation. Traditional scientific tools may be tethered to the classroom or lab, either due to practicality (cannot be transported outside the classroom) or cost (too risky to replace/repair if damaged or lost outside of the classroom). Smartphones could easily support the development of CBSE activities by allowing students to observe and measure phenomenon in a real-life setting outside of the classroom.

In 2021, Kaps et al. followed a university physics course that replaced pen-and-paper activities with investigative exercises where a smart device is used as the instrument of measurement. Traditionally this course would have distributed weekly worksheets, with four- or five-word problems to solve. These handouts were replaced with smartphone-based experimental exercises that could be performed at home for practice. A few examples of these activities are “The Tilting Smartphone” (using the smartphone gyroscope to measure inertia), “The Oscillation Balance” (constructing an oscillation balance using the smartphone, to calculate the mass of an unknown object), and “Using the Smartphone in a Torsion Pendulum” (constructing a torsional pendulum with the smartphone to calculate the directional moment). Overall, students indicated that the smartphone exercises increased their motivation in the class topics, as well as their interest. Curiously, student performance was higher in the pen-and-paper exercises, but researchers suggest this may be due to the higher complexity of the context, requiring greater curricular competency to get a correct answer. This is a fair hypothesis, given the smartphone exercises would be more authentic in nature, and therefore more challenging to answer than pen-and-paper problems. Conversely, the students’ conceptual knowledge was improved; this was due to the exercises being practical in nature, allowing the students a hands-on means to test out concepts they had learned in the lecture.

In a similar example, Kuhn & Müller (2018) studied the use of smartphones as a tool for measuring pendulum movements, a.k.a. harmonic mechanic oscillations, again tapping into the acceleration sensors of the device. This study discovered that the students who used smartphones to measure these mechanical movements demonstrated higher levels of interest and curiosity in the topic they were studying. In addition, the study concluded that despite concerns about smartphones being a distraction for students, reduced learning did not occur. Additional benefits were noted in a third study in 2019, where Gordon et al. observed students using smartphones as lux metres, measuring the intensity of light. In this investigation, 78% of student participants reported it was easier to take responsibility for their own learning.

Taken together, these three studies make up growing body of evidence that points to smartphones being instrumental in increasing student interest and curiosity in real-world science topics.

Cognitive Load Theory

In addition to the findings above, research suggests that smartphones can be used to tackle another issue that students face in science class: Cognitive overload. According to Sweller

(1998), Cognitive Load Theory is an instructional design theory that describes how the brain processes and stores information, an area of research highly relevant to curriculum design. It takes two main ideas into account: That the brain can process a limited amount of added information at one time and that known information can be accessed and processed at any time, with no limit. When designing lessons, activities, labs, and other educational interventions, teachers should work to optimize learning by lessening extraneous cognitive load. If a teacher does not remove non-essential information from the lesson, the student could be cognitively burdened with an excess of less-than-useful information, reducing the information that could be learned (Cognitive Load Theory, 2022). Smartphone applications have the capability of performing more work for the student by creating graphs, images, and other visual aids. By reducing the workload for the student, smartphones have the potential to reduce cognitive overload, allowing the learner to focus on the finer or more critical points in an investigation (Kuhn & Müller, 2018).

After considering the benefits that smartphones could offer and the potential drawbacks to their use in the classroom to keep in mind, further research is required to understand their validity as a scientific tool. First, it would be valuable to investigate what impact applied smartphone use can have on student interest and curiosity, in a different context than has already been researched. In addition, it seems practical to ask the students themselves what tool they prefer using. Given the general accessibility of smartphones, do students find smartphones easier to use compared to traditional science instruments? From a practical standpoint, it could be a financial advantage for schools if students preferred to use their own smart devices in the classroom, as school funding does not always permit for new tools to be purchased when the old ones break down. Conversely, if students preferred to use the traditional tools of measurement, this could be helpful information for schools and districts who are trying to increase engagement in STEM topics like science, math, engineering, and technology.

It would also be helpful to understand how using a smartphone as a scientific instrument (in place of a traditional tool) impacts a student’s drive to participate in non-academic digital multitasking. If the smartphone is being specifically applied as a tool, does this change how the student uses it in the class? Would the use of the smartphone as a tool increase or decrease media multitasking…or would this remain unchanged?

Research Questions

The primary research questions this study addresses are as follows:

1. How does using a smartphone as a scientific instrument (in place of a traditional tool) impact student curiosity and interest when measuring sound energy in a physics lab?

2. How does using a smartphone as a scientific instrument (in place of a traditional tool) impact a student’s drive to participate in non-academic digital multitasking?

3. Do students prefer using traditional equipment or smartphones as instruments when measuring sound energy in a physics lab?

To test these research questions, this study examines students’ experience in measuring sound with two different tools: A traditional decibel meter and a smartphone with a downloaded sound measuring application.

METHOD

Participants

This study took place in January 2022, at a secondary school in British Columbia, Canada. A total of two grade 10 science classes participated in the lab, with 26 and 28 students in each class respectively. Of these fifty-four students, twelve students did not submit completed permission forms and fourteen students either completed the feedback form incorrectly, completed only one of the two, or did not complete either. In total, feedback was processed from twenty-eight students, fourteen from Class 1 and 14 from Class 2. Given these factors, the response rate for this experiment was 50%. This was a convenience sample, as these were classes that this researcher was teaching at the time that the study was conducted.

Learning Activity

Space and space technology are curricular topics in the British Columbia Science 10 curriculum; these students spend several weeks studying the origins and components of the universe. One of these topics is the study of Dark Matter, a little-understood component of the known universe. As part of their studies, students learn about the Xenon 1T Dark Matter Experiment that operates out of the INFN Laboratori Nazionali del Gran Sasso in Italy. The Xenon1T Dark Matter detector uses Xenon gas that scintillates if any matter passes through it, with a double array measuring the scintillation. This laboratory is very isolated; an assumption of the Xenon1T experiment is that only radiation and dark matter would be able to penetrate the thick layer of mountain that surrounds the lab itself, each of which would scintillate at a different intensity (Wiesner et al., 2020). Therefore, scientists would be able to observe a particle of dark matter passing through the Xenon gas.

It is not possible to replicate the Xenon 1T experiment in a classroom; this can present challenges to teachers who are trying to teach more intangible topics in the classroom. However, Wiesner et al (2020) developed an analogous lab for young students who participate in their Saturday Morning Astrophysics program at Purdue University. In this lab, scintillation of Xenon gas will be replaced with sound, and the two light arrays will be replaced with traditional decibel meters and smartphones. Students will be using the sound-measuring devices to measure the sound created by two differently weighted balls dropped into a basket of ping pong balls.

Laboratory Procedure

In the first stage of the lab, students are given some background information on the Xenon 1T Dark Matter Project. They are then asked to answer to questions to assess their understanding of the Xenon 1T project in general, and how the lab they will be completing is analogous to that experiment. Students are next asked to set up their apparatus: A basket is filled with ping pong balls and a meter stick is attached securely to the side (see Figure 1). They will have two balls to drop, one heavier and one lighter. They will drop each ball from three different heights (25 cm, 50 cm, and 100 cm), repeating each drop height three times. Prior to each drop, students will note the baseline noise of the classroom (dB min) with the sound-measuring device, and then how much sound was produced when the ball hit the ping pong balls (dB max); the dB min will be subtracted from the dB max to remove extraneous noise. Students will note this difference in a table (see Table 1) so that results can be compared later on.

Figure 1 – A student sets up their apparatus, filling a basket with ping pong balls and securing a metre stick to the side of the basket to measure drop height

Table 1 - Data Collection Table

TABLE 1: SMALL BALL TRIAL DATA AND CALCULATIONS			
Initial Height	**Test #1**	**Test #2**	**Test #3**
25	dB difference =	dB difference =	dB difference =
50	dB difference =	dB difference =	dB difference =
100	dB difference =	dB difference =	dB difference =

TABLE 2: LARGE BALL TRIAL DATA AND CALCULATIONS			
Initial Height	**Test #1**	**Test #2**	**Test #3**
25	dB difference =	dB difference =	dB difference =
50	dB difference =	dB difference =	dB difference =
100	dB difference =	dB difference =	dB difference =

Students will have the opportunity to use two different sound-measuring devices: A portable decibel meter (a traditional tool for measuring sound) and a smartphone, using a free downloaded application. To accurately assess student experience when using these sound-measuring devices, students are asked to repeat the above procedure twice: Once with a decibel meter and once using their personal smartphone (See Figure 2 for a comparison). Given there were two classes participating in the study, there was the opportunity to assess whether order of tool use would impact tool preference and experience (topic interest, curiosity, etc.…). Therefore Class 1 would do the first set of measurements with the decibel meter, and then repeat using their smartphone. Class 2 would do the opposite, completing the first trial using their smartphone, and then repeat the procedure with the decibel meter. For reference, the full lab handout can be found in the Appendix.

Figure 2 - A side-by-side comparison of the Decibel X interface (left) used on a smartphone, with that of the decibel meter (right)

Instrument and Data collection

A 5- point Likert scale survey was developed to measure student experience during the lab (see Table 2), where students could select answers in a range from “Strongly Disagree” to “Strongly Agree”. Questions from the survey are adapted from two previously established scales used in research. Questions 1 to 7, relating to interest and curiosity in classroom topics, are adapted from Hochberg et al.’s 2018 study, “Using Smartphones as Experimental Tools—Effects on Interest, Curiosity, and Learning in Physics Education”. Questions 8 to 12, relating to media multitasking, are adapted from Chang’s 2017 study, “Why do young people multitask with multiple media? Explicating the relationships among sensation seeking, needs, and media multitasking behavior”. Question 14, asking students to confirm that they have a smartphone that they bring to class, was included to confirm if there are any students who do not possess a smartphone, and therefore whose data would need to be excluded from the

Table 2 - Likert Scale Survey Questions and Categories

	Question	**Category**
Q1	In my leisure time, I engage in topics that are related to the study of space (beyond what is in my homework)	Interest
Q2	Outer space is an important topic for young people to learn about	Interest
Q3	The outer space topics that we cover in class make sense to me	Interest
Q4	Our teacher makes outer space an interesting and relevant topic to study	Interest
Q5	Learning about outer space is fun for me	Curiosity
Q6	The labs that we have done have piqued my interest about space	Curiosity
Q7	I have researched outer space topics outside of class, to learn more about what were learning in class	Curiosity
Q8	I focus exclusively on the space labs we do in class without feeling distracted by my smartphone	Media multitasking
Q9	I use a smartphone for entertainment during science labs	Media multitasking
Q10	I use a smartphone during lab time because I feel nervous about working in groups	Media multitasking
Q11	I use a smartphone during lab time because I feel like I don’t have anything to contribute to group work	Media multitasking
Q12	I use a smartphone during lab time because I am uncertain as to what I should be doing during the lab	Media multitasking
Q13	I have a smartphone that I bring to class with me	Smartphone as tool
Q14	A smartphone can be a helpful educational tool	Smartphone as tool
Q15	I am more comfortable using a smartphone as a measurement tool than a traditional scientific measuring device.	Smartphone as tool
Q16	I use a smartphone in class to look up relevant class material	Smartphone as tool
Q17	I use a smartphone as a tool to complete lab activities	Smartphone as tool

analysis. Questions 13, and 15 to 18 were included to gain a better understanding of students' perceived comfort with the tools and the usefulness of traditional tools and smartphones. The Likert scale surveys were completed after completing with full lab with one of the instruments of measurement and submitted directly following their completion so as not to influence the second trial and survey that followed. In Class 1 they were completed once after completing the lab with a decibel meter, and then once again after completing the lab with a smartphone; in Class 2 the order of the tools was switched, but the surveys were completed at the same points.

In addition to the quantitative data collected, a final qualitative question was asked of students once the lab was completed in its entirety: *"In this lab, you used both a decibel meter and smartphone to measure sound. Which tool did you prefer using and why? (Please answer in as much detail as possible)"*. The purpose of asking this qualitative question was to gather more specific information about tool preference and allow the students to describe their preferences in their own words.

Data Analysis

The Likert scale survey information was compiled in Microsoft Excel. The data was first examined within each class. For Class 1, the first survey served as the baseline, measuring the students' general interest, curiosity, and tendency to participate in media multitasking when using a traditional tool of measurement. The second survey, completed after repeating the lab with a smartphone, was used to examine if a change (an increase or decrease) in interest, curiosity, or multitasking occurred after repeating the lab with the smartphone. The results of these surveys were compared and a t-test (α=0.05) was applied to assess for a statistically significant change. In Class 2, the students completed the first survey after completing the lab with a smartphone, and then again after repeating the lab with a decibel meter. These results were analyzed with the same t-test as Class 1, to assess for change.

An additional level of statistical analysis was applied, where the averages of question categories (Interest, Curiosity, Engaging in Media Multitasking, and Perception of a Smartphone as a Useful Tool) were calculated, and a t-test again applied to see if there was a change between the first and second surveys.

The qualitive data was also collected and compiled in Microsoft Excel, and inductive coding was used to categorize and sub-categorize the comments. The two categories were based primarily on preference (Decibel meter or smartphone); the subcategories did overlap to a small degree between the categories, but there is also some degree of uniqueness.

The results of the qualitative data were examined and counted to determine which tool was preferred, and what were the primary reasons for that preference. A t-test was applied to see if there was a difference in preference between the two classes. Should a student indicate more than one reason, then those reasons were coded individually.

If a student completed Survey 1 but not Survey 2 (or vice versa), then this student's answers were removed from the comparative analysis between Classes 1 and 2. However, there were cases where students had not correctly completed Surveys 1 and/or 2, but had correctly completed Survey 3, the qualitative question. In this case, provided the student had completed the lab in full, their Survey 3 answers were analyzed with the other responses, as these results would not be impacted by not having completed the other two surveys incorrectly.

RESULTS

Quantitative Analysis

The results of the mean individual question analysis can be found in Table 3, below. Assuming an $\alpha = 0.05$ value for the t-test, there was no notable increase or decrease to be found for any individual question. There were a few questions that came close (Curiosity Q1; Smartphone as Tool Q5; Interest Q4; Smartphone as Tool Q1), however none were sufficiently significant to demonstrate that a change in interest, curiosity, multitasking behaviours, or the students' perception of a smartphone as a useful tool, had occurred.

Table 3 - Individual Question Analysis

Class 1	**After decibel meter**	**After smartphone**	**Increase/ Decrease**	**p-value**
Interest Q1	3.14	3.29	0.14	0.43
Interest Q2	4.07	4.21	0.14	0.34
Interest Q3	4.14	4.14	0.00	1.00
Interest Q4	4.64	4.50	-0.14	0.34
Curiosity Q1	4.00	4.29	0.29	0.10
Curiosity Q2	3.79	3.93	0.14	0.43
Curiosity Q3	3.00	3.29	0.29	0.26
Multitask Q1	4.07	3.86	-0.21	0.34
Multitask Q2	2.86	2.79	-0.07	0.88
Multitask Q3	2.14	2.14	0.00	1.00
Multitask Q4	1.57	1.79	0.21	0.34
Multitask Q5	1.79	2.00	0.21	0.51
Confidence Q1	4.07	4.43	0.36	0.21
Smartphone Q1	4.86	4.79	-0.07	0.34
Smartphone Q2	4.71	4.69	-0.02	1.00
Smartphone Q3	3.43	3.21	-0.21	0.51
Smartphone Q4	3.86	4.14	0.29	0.10
Smartphone Q5	4.07	4.50	0.43	0.23
Class 2	**After smartphone**	**After decibel meter**	**Increase/ Decrease**	**p-value**
Interest Q1	3.21	3.21	0.00	1.00
Interest Q2	3.93	4.00	0.07	0.58
Interest Q3	4.07	4.07	0.00	1.00
Interest Q4	4.36	4.21	-0.14	0.16
Curiosity Q1	3.93	4.07	0.14	0.43
Curiosity Q2	3.50	3.57	0.07	0.67
Curiosity Q3	2.79	3.00	0.21	0.34
Multitask Q1	3.57	3.50	-0.07	0.79
Multitask Q2	2.64	2.79	0.14	0.63

Multitask Q3	2.00	1.93	-0.07	0.67
Multitask Q4	1.71	1.79	0.07	0.75
Multitask Q5	2.00	1.86	-0.14	0.34
Confidence Q1	4.36	4.21	-0.14	0.34
Smartphone Q1	4.93	4.79	-0.14	0.16
Smartphone Q2	4.64	4.43	-0.21	0.08
Smartphone Q3	3.57	3.50	-0.07	0.79
Smartphone Q4	4.07	3.79	-0.29	0.26
Smartphone Q5	3.93	3.86	-0.07	0.75

In the next set of statistical analyses, individual questions were condensed by category, and the average of each category was calculated; these results are summarized in Table 4. Two changes of note did occur:

- Curiosity values increased after the second repetition of the lab. In the case of the students who first completed the lab with the smartphone and then the decibel meter, the increase was not statistically significant *(p = 0.07),* but with students who set a baseline with the decibel meter first, and then repeated with the smartphone, the increase was statistically significant *(p = 0.04).*
- In the students who first set a baseline with the decibel meter and then repeated with the smartphone, there was no meaningful change to their perception of a smartphone as a useful tool. However, in the class that started with the smartphone and then repeated with the decibel meter, there was a statistically significant decrease in the perception of a smartphone as a useful tool *(p = 0.02).*

Table 4 - Category Analysis

	Class 1			**Class 2**		
	Survey #1	**Survey #2**	**p-value**	**Survey #1**	**Survey #2**	**p-value**
Interest Mean	4.00	4.04	0.64	3.89	3.88	0.72
Curiosity Mean	3.60	3.83	0.04	3.40	3.55	0.07
Multitasking Mean	2.49	2.51	0.75	2.39	2.37	0.80
Smartphone as Tool Mean	4.19	4.27	0.53	4.23	4.07	0.02

Qualitative Analysis

Analysis of the open-ended question “Which tool did you prefer using, and why?” revealed two categories (Decibel Meter vs. Smartphone Preference) and fourteen subcategories. These categories and subcategories (with examples) are described in Table 5, below.

Table 5 – Inductive Coding for Tool Preference Categories

Category	Sub-Category	Example
Decibel Meter Preference	Accuracy	"…there is a specific min and max and you don't have to guess so its more accurate"
	Less distracting	"…more simple, and less distracting"
	Task Specificity	"…it was designed to measure sound"
	Ease of Use	"…the decibel meter was very easy to use…only has 3 buttons on the other hand the app on the phone has so many buttons
	Simplicity	"…was very easy to use and simple"
	Technical Challenges	"…also my phone kept turning off"
	Safety	"…felt safer"
	Ergonomics	"…it is smaller and fits into my hand
Smartphone Preference	Ease of Use	"…[my phone] was easier to use"
	Accuracy	"…it was more accurate and shared the information after"
	Familiarity	"…and comfortable use"
	Accessibility	"…You don't usually see people carry a decibel meter or any traditional study tool with them. Public schools can't afford to have a lot of these tools for everyone, so it is better to use smartphone since almost everyone has a phone. And the app to use are free to download"
	Lower Perceived Cost	"…and it is less costly than science instruments"
	Convenience	"…because it's more convenient to use"
	Varity of Applications	"…there are vary (sp) of apps to select that can measure sound"
	Simplicity	"it is more straight-forward when it comes to its usage"
	Time Saver	"…I didn't have to listen to instructions unlike the decibel meter, so it was obvious that we saved quite a lot of time when we tried our experiment with cell phone"

The first was simply based on the students’ indicated preferences, the result being that the decibel meter was preferred by most students in both classes. In Class 1, decibel meters were preferred by 24 out of 38 students, 63% of the class. In Class 2, decibel meters were preferred by sixteen out of 23 students, 70% of the class. In the t-test applied to compare the preferences of both classes, the p-value was calculated to be 0.66, indicating that the two classes did not differ significantly in their tool preference. Therefore, overall tool preference category was examined collectively to include both classes. Overall, the traditional tool was preferred by 59% of students, compared to 32% who preferred the smartphone and 9% of students not indicating a preference either way. A summary of results for the preference categories and sub-categories can be found in Table 6.

Table 6 – A Summary of Tool Preferences and Reasons (per class and combined)

		Class 1		**Class 2**	
Decibel Meter Preference Categories	Accuracy	5	21%	7	44%
	Less distracting	5	21%	2	13%
	Task specificity	4	17%	1	6%
	Ease of use	4	17%	5	31%
	Simplicity	3	13%	0	-
	Technical challenges	1	4%	0	-
	Safety	1	4%	0	-
	Ergonomics	1	4%	1	6%
	Total	24		16	
Smartphone Preference Categories	Ease of use	1	7%	4	57%
	Accuracy	2	14%	1	14%
	Familiarity	1	7%	0	-
	Accessibility	2	14%	0	-
	Lower perceived cost	3	21%	0	-
	Convenience	2	14%	1	14%
	Variety of applications	1	7%	0	-
	Simplicity	1	7%	1	14%
	Time saver	1	7%	0	-
	Total	14		7	

	Class 1 and 2 combined		
	Decibel Meter Preference	20	59%
	Smartphone Preference	11	32%
	No Clear Preference	3	9%

With the group that began with the smartphone and then repeated the lab with the decibel meter, there was a slightly greater preference indicated for the more traditional tool. However, given that the t-test indicated that there was not a significant difference in preference between the two classes, the numbers for both classes were combined, and the rationales were collectively analyzed, with a summary of this analysis found in Table 7. For students who preferred the decibel meter, the top reason was accuracy (mentioned 30% of time by students who preferred the decibel meters), followed by ease of use (23%), less distracting (18%), and task specificity (13%), meaning the student perceived that this tool was designed for exactly this task, and should be used as such. The lesser mentioned, though still notable reasons included simplicity (8%), ergonomics (5%), safety (3%), and technical challenges (3%).

Table 7 - Analysis of both classes combined

Decibel Meter Preference			Smartphone Preference		
Accuracy	12	30%	Ease of Use	5	24%
Ease of use	9	23%	Accuracy	3	14%
Less distracting	7	18%	Convenience	3	14%
Task specificity	5	13%	Lower perceived cost	3	14%
Simplicity	3	8%	Accessibility	2	10%
Ergonomics	2	5%	Simplicity	2	10%
Safety	1	3%	Familiarity	1	5%
Technical challenges	1	3%	Time saver	1	5%
Accessibility	0	-	Variety of applications	1	5%
Convenience	0	-	Ergonomics	0	-
Familiarity	0	-	Less distracting	0	-
Lower perceived cost	0	-	Safety	0	-
Time saver	0	-	Task specificity	0	-
Variety of applications	0	-	Technical challenges	0	-
Total	40		**Total**	21	

The reasons for preferring a smartphone were similarly analyzed, with the top reason being ease of use (24% of the comments by smartphone preferers), followed by accuracy, convenience, and lower perceived cost (each at 14% of comments). The less popular reasons given were accessibility and simplicity (each at 10% of comments) and familiarity/time saver/variety of applications available (each at 5% of comments).

Among both groups, accuracy and ease of use were the top reasons given for their tool of choice, at 27% and 16% of comments respectively, with decibel meter preferers prioritizing the former and smartphone users prioritizing the latter. Other preferences indicated beyond these tended to be tied to a particular tool, with smartphone preferers prioritizing convenience, lower perceived cost, and accessibility, while decibel meter preferers appreciating the lower distraction factor and the fact that the decibel meters were designed for such a task.

DISCUSSION

In this study the following research questions were investigated:

1. How does using a smartphone as a scientific instrument (in place of a traditional tool) impact student curiosity and interest when measuring sound energy in a physics lab?

2. How does using a smartphone as a scientific instrument (in place of a traditional tool) impact a student's drive to participate in non-academic digital multitasking?

3. Do students prefer using traditional equipment or smartphones as instruments when measuring sound energy in a physics lab?

Once the analysis was complete, the following research conclusions were reached:

- Smartphones increased student curiosity in science topics
- After first using a smartphone as a tool and then following with a decibel meter, students were less inclined to perceive the smart device as a valuable tool
- Using a smartphone as a tool did not seem to impact students' inclination to digitally multitask
- Students seemed to prefer using traditional tools to smartphones during a science lab, for varied reasons

In this study many students preferred decibel meters to smartphones. This is an important consideration for schools, departments, and teachers when it comes to curriculum planning, lesson implementation, and budgeting. The accessibility of smartphones in the classroom may be what is driving educators to consider using these devices instead of traditional tools; schools to may also be driven to encourage the use of smartphones when faced with the cost of purchasing equipment to replace aging technology (Maciel, 2015). But, if science teachers wish to increase curiosity in science at their schools, it would be well-advised for departments to continue investing in functioning scientific instruments to foster that curiosity.

Regardless of indicated preference, do smartphones have the potential to increase curiosity and interest in lab activities, as has been demonstrated by Kaps et al. in 2021 and Kuhn and Müller in 2018? It does appear in this study the smartphones had a positive impact when it comes to optimizing student curiosity in physics. It should be noted again that in Class 2, where the smartphone was used first and then the lab repeated with the decibel meter, there was also an increase in curiosity as well though not as statistically significant as in the case of Class 1. It is possible that upon the second repetition of the lab the students' curiosity level was increased, due to a better understanding of the concepts or the lab procedure, but that using the smartphone did increase that curiosity level to a more significant degree. However, while smartphones may have contributed to an increase in curiosity, interest in the lab topic remained unchanged overall. The results of this study are still potentially valuable for all educators: Harnessing the real-world potential of smartphones can uncover options for educators who are hoping to bring more context-based learning opportunities into their own classrooms. But further research may be necessary to further identify how interest and curiosity, two areas that are intertwined, could be impacted by the useful application of these smart devices.

The results of the Media Multitasking questions were similarly unchanged, though the context of this lack of change is different than in the previous two question categories. Because students did not significantly change their multitasking responses, this suggests that while the smartphone did not reduce media multitasking during the lab, it also did not increase it. This is noteworthy, as previous research (Bowman et al., 2010) had concluded that students believe themselves to be more competent multitaskers than they truly are. This would suggest that if given permission to use a smartphone as part of an investigation, students might have felt inclined to use it for non-lab activities, we may have seen a significant increase in some of their Multitasking answers, for example "I use a smartphone for entertainment during science labs", "I use a smartphone during lab time because I feel nervous about working in groups", "I use a smartphone during lab time because I feel like I don't have anything to contribute to group work", and "I use a smartphone during lab time because I am uncertain as to what I should be doing during the lab". Conversely, we may have seen a decrease in the question "I focus exclusively on the space labs we do in class without feeling distracted by my smartphone." In both cases there was no notable change, suggesting that smartphones may not be the dangerous tool of distraction they are often perceived to be. This raises the question of intentional smartphone use in class: If a smartphone is given an intentional purpose by the classroom teacher, is it possible that this could reduce the potential for distraction? This would be another area for further research. Another question that begs closer examination is why students multitask with their smartphones in the first place. Anecdotally, this teacher has heard other teachers mention that students are "bored", "easily distracted", and "lacking in motivation". But even without comparing before and after survey results, this study revealed that many students multitask for reasons that seem more related to confidence and uncertainty, based on how they were answering the Multitasking questions even initially. This bears further scrutiny, so that as educators we can better understand the reasons our students hide behind their devices.

The Multitasking category also revealed one of the shortcomings of the instrument. Because of the phrasing of the Multitasking questions, student answers could work in contrast to cancel each other out. For example, if we are merging Multitasking questions, “I use a smartphone during lab time because I feel like I don’t have anything to contribute to group work”, and “I focus exclusively on the space labs we do in class without feeling distracted by my smartphone” could potentially yield opposite results, and thus if the results of these two questions are combined we would not be able to perceive whether the overall change was positive or negative, if any occurred at all. In this study, there was no change in the individual Multitasking questions, and so it makes sense that the individual questions should be the focus of the analysis, as the merged category analysis would have been impacted by this issue. In a future study, it would make sense to re-word questions so that this effect did not occur. It might also be helpful to reword each multitasking question to produce a clearer picture for the investigator. The questions proved to be quite general when it came to multitasking behaviour, and more specific questions like “I used my phone for non-academic purposes during this lab”, for example, would be more appropriate for future research.

The final category of survey questions addressed how useful students perceive a smartphone to be as a tool. Like the Interest and Curiosity categories, when these questions were analyzed individually there was not a significant change for each question. However, when all questions in the category were merged, there was a meaningful change noted. For the students who first completed the lab with the smartphone and then repeated the lab with the decibel meter, there was a decrease in the students’ perception of smartphone usefulness. This implies that after completing the lab with a traditional instrument, the students saw greater value in that traditional instrument than the smartphone they had initially used. Interestingly there was no change noted in Class 1, who began the experiment with the decibel meter and then repeated with the smartphone. This result brings up more questions: Do students not value smartphones as much as educators believe them to? Does this result depend on the type of traditional tool we are referring to? Are smartphones more complicated or flawed than traditional devices? Do students tire of being asked to use their smartphones for educational tasks? It would be helpful to know more about what drives potential preferences for certain tools. These are all questions that could be more fully investigated in the future, but some clues may be given below, in the qualitative analysis of this study.

With students who indicated a preference for using a decibel meter in the lab, the top reason given for this choice was that the decibel meter was more accurate than the smartphone. It should be noted in this case that while higher accuracy is perceived by the students, the students were using only one tool at a time, and thus could not confirm that the tool was in fact more accurate. This point also stands for those students who preferred smartphones and indicated accuracy as a primary selling point - it was the second-most mentioned reason by these students. This is where deeper inquiry would have been helpful, to elaborate more on what students perceived as accuracy. In the original plan for this study, the quantitative and qualitative surveys would have been followed by one-on-one interviews with willing participants. Unfortunately, the data collection of this study took place in January 2022, at the peak of the Omicron variant of the Coronavirus pandemic in Canada. Due to a combination of school closures, a high rate of student absence, and semester turnover, the one-on-one interviews could not be pursued. Still, the fact that accuracy was highly valued by both decibel meter and smartphone preferers indicates that all students assign worth to devices that give them clear and concise answers.

Students who preferred decibel meters additionally noted that the tools were easy to use and less distracting. As summarized by one student: “I preferred the decibel meter because it was easier to point and was much easier to set up. That was it is intended purpose so for me it felt more accurate. For me it just felt easier, more simple, and less distracting”. As noted by another, “The decibel meter only has 3 buttons on the other hand the app on the phone has so many buttons”. These are both fair points, and while a smartphone may be a familiar object, it is by no means simpler. Most sound-measuring applications (for example Decibel X) have a simple interface, though tends to have more features (graphs of sound output, a visual of sound range, etc.…) compared to the traditional decibel meter. These features are not overly complicated and can potentially work to reduce cognitive load by doing some of the work for the students. However, a side-by-side comparison of the smartphone application and the decibel meter interface does show the latter to be simpler (refer to Figure 2 in Methods section). Further, to navigate to the smartphone application students may be required to enter their smartphone security code, often multiple times depending on their security settings. These trivial things add to the overall load that students manage with when using the application, and so it is fair that many students would prefer the tool with the simpler interface. Educators should take these factors into account when trying to make use of smartphones in the classroom; they may be ubiquitous, but it does not necessarily mean they are the easier tool to use.

For students who indicated a preference for decibel meters, the third and fourth most frequently mentioned reasons were that these tools were less distracting and designed for this particular purpose. Like the Multitasking category in the quantitative analysis, these two rationales seem to point to students' awareness of how distracting smartphones can be. Contrary to the concern previously established in research that young people overestimate their multitasking abilities (Alghamdi, et al., 2020), many students in this class seemed quite aware of the cost of task-switching, as it informed a portion of the class's preferences. But what raised this awareness in the first place for these students? This would have been another area where one-on-one interviewing could have been valuable, to further probe the students' perception of the distractibility of a tool. Is it that the interface itself is less distracting? Do the decibel meters allow students to get the job done faster, and thus they perceive there are fewer opportunities for distraction? This last idea may have been a factor in this lab: Due to the pandemic restrictions that were currently in place in the school, students were not able to complete the lab in groups as had been previously planned, but instead had a window of time to complete each section of the lab independently. Because of the lack of available extra equipment, this meant that materials were being rotated between students quite quickly and sanitized between uses for safety reasons. As a result, students were observably focused on the task at hand, knowing that they needed to complete their procedure as quickly as possible so that all students could complete the lab within the given period. It is possible then that the intense nature of the lab (or that there were periods of waiting/analyzing punctuated with intensive periods of testing) removed the opportunity for distraction and media multitasking, leading students to value the tool that allowed them to work as efficiently as possible? This is yet another area where further research could be valuable: Does lab intensity reduce digital multitasking?

There were two more categories of note for students who preferred smartphones: those who indicated smartphones were convenient and those who indicated that smartphones had a lower (perceived) cost to the user, both mentioned in 14% of the comments. The mention of convenience is not surprising – students themselves are aware of the omnipresence of smartphones in daily lives. As explained by one student:

> I would prefer to use a smartphone, since it is easy to access, free app, and most people have smartphone. You don't usually see people carry a decibel meter or any traditional study tool with them. Public school can't afford to have a lot of these tools for everyone, so it is better to use smartphone since almost everyone has a phone. And the app to use are free to download.

The student's awareness of public-school funding issues is noteworthy – it demonstrates that (many) students are not blind to the lack of funding available for some schools and teachers to buy and maintain appropriate equipment. But also striking is the student's perception of the value of a smartphone compared with the scientific tools used in class. The decibel meters used for this investigation were purchased for approximately $25.00 Canadian dollars apiece on Amazon. Naturally, this is not the representative cost of all science equipment that could be purchased for schools, as some science equipment can be valued at hundreds, if not thousands, of dollars. But comparably, the average smartphone is more expensive. In May 2022, a new iPhone 13 (128 GB) can be purchased for $1399.00 CAD (Best Buy Canada, 2022). This is not to say that all students in public school possess this smartphone; there a wide availability of different models and second-hand options. Students are often inheriting hand-me-down options from parents, siblings, or elsewhere. Still, these tools can cost as much as a computer, and this does not yet take into consideration the ongoing cost of owning a smartphone; wireless costs in Canada are amongst the highest in the world (Hopper, 2021). So, the perception of the smartphone being the more affordable option is interesting. Like previous categories, these comments would have benefited from further investigation through one-on-one interviews, to better understand students' perception of tool affordability.

This brings into question who should be bearing the cost of education – the parents and custodians of students, on an individual level? Or the schools and districts based on funding received from provincial jurisdictions? In British Columbia, Canada, where this research has taken place, there has been an ongoing battle between teachers and the province as to whether the provincial educational system is in economic crisis. In a report by Canadian Centre for Policy Alternative (2016), Alex Hemingway describes that funding for education has proportionally decreased in comparison to other provincial budgetary items and sits well below the federal average for per-student spending. In addition, he notes the extreme strategies that invested parties are taking to compensate for a lack of adequate financial support:

> [Following] a familiar strategy of concealing taxes by calling them "fees," the education system continues to rely on parents to fundraise for things like playgrounds, classroom technology and hot lunches, and to pay a growing array of fees for field

> trips, supplies and transportation. Teachers continue to subsidize school funding by paying large sums out-of-pocket for classroom supplies. Most concerning, class sizes are growing and classrooms host an increasing number of students with learning challenges or other special needs—with too few staff and resources made available to support them.

So, in the bigger picture, should we be relying on students' smartphones as tools to make up for a lack of educational funding? Even if they could be shown to increase interest and curiosity in science topics by allowing students to investigate within a real-world context, educators should be wary of depending too heavily on these devices given that extensive reliance could set a dangerous precedent when it comes to educational funding.

A final factor to consider before educators make their own decisions about smartphone use in classrooms: How are adults using these tools in everyday life? It is reasonable to assume that young people will emulate what they see in older adults, and that smartphones are just as ubiquitous in adult life as they are in the lives of students. How can we ask students to put their phones away in class when adults are using theses devices in the workplace, in restaurants, and at the dinner table, amongst other places? It is possible that the answer to how smartphones can be used in the classroom is part of a bigger question: What place do we want these devices to hold in our everyday lives, and are we willing, as adults, to model how we want these tools to be used? Perhaps like in the classroom, a balance of moderate smartphone use combined with the exploration of other real-world tools, is the answer.

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AUTHOR’S DECLARATION

I hereby declare that I have written this thesis independently and that all contributions of other authors and supporters have been referenced. The thesis has been written in accordance with the requirements for graduation theses of the Institute of Education of the University of Tartu and is in compliance with good academic practices.

Signature: Date: May 22, 2022

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APPENDIX

Student Laboratory Handout

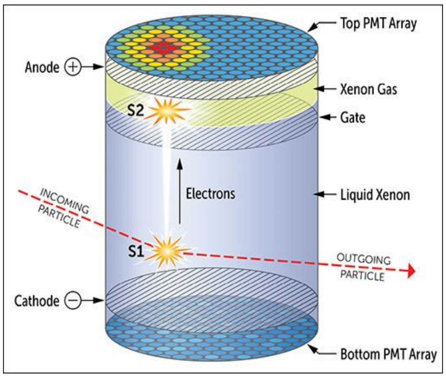
Introduction: What is Dark Matter?

A large portion of the universe is made up of matter that we cannot see – Dark Matter and Dark Energy are speculated to make up about 27% and 68% of the universe respectively. This means that what we see makes up only 5% of the universe!

We know that Dark Matter exists because of the movement of galaxies. The rotation of stars and star systems around galaxy centres should be predictable – galaxies are massive, and their pull of gravity keeps stars and star systems rotating around the centres at predictable speeds. However, scientists have observed that some stars rotate around the edges of galaxies at such high speeds that the gravity of the galaxy shouldn't be able to hold them anymore, and they should hurtle off into space…but they don't! This means that there must be much more mass in the galaxy than we are able to measure. Because we can't currently observe what this extra mass is that is holding galaxies together by gravitational pull, we call this mysterious mass "Dark Matter".

How do we observe or detect Dark Matter?

There are currently a lot of theories about what Dark Matter is or isn't…it's very hard to observe and measure something we can't see. So, researchers are tasked with designing experiments that can detect these unseen particles. One of these experiments is **XENON1T** experiment, located at the Laboratori Nazionali del Gran Sasso underground laboratory in Italy.



The XENON1T experiment takes place deep under the Gran Sasso Mountain range. It consists of a large vat of pure liquid Xenon, along with a top layer of Xenon gas and two arrays (top and bottom) to measure any interactions that take place in the chamber. (See diagram)

Xenon was selected for several reasons:

- It has a **high molecular mass**, and so would be an excellent target for anything moving through the chamber
- It is an **excellent scintillator**, which means it lights up when hit by a particle or ray
- Xenon can be produced to a **high purity level**, meaning there would not be an excess of radiation in the vat

Scientists have hypothesized that Dark Matter particles could potentially be observed to move through the chamber: **If a Dark Matter particle did enter the chamber, it would likely collide with one or more molecules of Xenon, and scintillation would be observed by the arrays.**

One complication a dark matter scientist would have to contend with is fact that other ("normal") radiation could also move through the chamber. Even though the apparatus itself is within a mountain, and protected by layers of material, it is still possible that beta and gamma reactions could still occur – and researchers do need to be able to distinguish between these and any Dark Matter interactions that take place. They know how much energy (or scintillation) could be emitted from a normal radiation particle moving through the vat – it's quite high! They speculate based on current thinking that Dark Matter particles are quite heavy, and only interact with normal, visible matter very weakly – so they believe that the energy/scintillation produced by Dark Matter hitting a Xenon particle would be quite a bit lower. Differentiating these two energies produced would be key to confirming that Dark Matter did indeed move through the chamber.

Observing Dark Matter in the classroom – What are we doing in this lab?

The goal of this lab is to introduce the idea of trying to measure or find something that you can't see. In the XENON1T experiment they used a vat full of liquid xenon and an array that measures the flashes of light that occur when particles fly through the xenon. We can't see the dark matter particles (or any other particles) that fly through the vat, but we can measure the flashes of light.

In this lab, instead of trying to measure **scintillation (or light)** as the XENON1T project does, we will be measuring **sound**. We will be dropping two differently weighted balls to measure the differences in the sound when it lands in a basket of ping pong balls. The idea here is to try to see what it's like to observe something without relying on our vision, just like the Dark Matter scientists do. Because we think that Dark Matter particles are quite heavy, we are going to use the heavy ball to represent them, and the lighter ball will represent any other light radioactive particle. We are going to drop these two balls into a basket to measure the sound they make when they hit the ping pong balls.

Materials

- Large plastic basket
- Ping pong balls
- 1 large ball
- 1 small ball
- Metre stick
- Decimetre
- Smartphone

Pre-Lab: Background information and understanding the lab

- Carefully read the Introduction, Materials, and Procedure below **first**
- Before proceeding with the lab, answer the 3 questions below. Show your answers to the teacher to receive your lab materials

1. **In 1-2 sentences, briefly describe the purpose of the XENON1T lab in Italy?**
2. **In 1-2 sentences, briefly describe what we are trying to accomplish in the lab today, relating to Dark Matter?**

Part 1 – Measuring Sound with a Decimeter

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1. Ensure your ping pong balls are in the basket
2. Secure your metre stick with one end in the basket, keeping upright so that height of drop can be measured (see photo to right)
3. Position the decimetre as close to the ping pong balls as possible for optimal sound measurement
4. For each drop, note the baseline class noise level in your chart *(dB min)*
5. Drop the smaller ball from 25 cm height into the ping pong balls, and note the maximum decibels achieved during drop in your chart *(dB max)*. Repeat two more times from this height, for a total of 3 tests.
6. Now, proceed to drop the small ball from 50 cm and 100cm from ground, taking note of dB min and max in your chart. Make sure to repeat each height 3 times.
7. Repeat steps 5-6 using larger ball. Note all measurements in your chart.
8. Take the time to complete Table 1 and 2, calculating dB difference for all trials, using the formula below:

dB difference = dB max – dB min (baseline)

TABLE 1: SMALL BALL TRIAL DATA AND CALCULATIONS

Initial Height (cm)	**Test #1**	**Test #2**	**Test #3**
25	dB min = dB max = dB difference =	dB min = dB max = dB difference =	dB min = dB max = dB difference =
50	dB min = dB max = dB difference =	dB min = dB max = dB difference =	dB min = dB max = dB difference =
100	dB min = dB max = dB difference =	dB min = dB max = dB difference =	dB min = dB max = dB difference =

TABLE 2: LARGE BALL TRIAL DATA AND CALCULATIONS

Initial Height (cm)	**Test #1**	**Test #2**	**Test #3**
25	dB min = dB max = dB difference =	dB min = dB max = dB difference =	dB min = dB max = dB difference =
50	dB min = dB max = dB difference =	dB min = dB max = dB difference =	dB min = dB max = dB difference =
100	dB min = dB max = dB difference =	dB min = dB max = dB difference =	dB min = dB max = dB difference =

Part 2 - Analysis

- Return your materials to the teacher to be sanitized
- Answer the follow up questions below

1. **Describe the accuracy of your trials – were there any numbers that stood out or didn't make sense? Can you provide an explanation for the irregularities?**
2. **Draw your experimental apparatus, below**

Follow-up Survey #1

Complete only once you have completed Part 1 and 2 of the labs and before you begin Part 3

Name:

	Strongly Disagree	**Disagree**	**Unsure/ no opinion/ not relevant**	**Agree**	**Strongly Agree**
In my leisure time, I engage in topics that are related to the study of space (beyond what is in my homework)	☐	☐	☐	☐	☐
Outer space is an important topic for young people to learn about	☐	☐	☐	☐	☐
The outer space topics that we cover in class make sense to me	☐	☐	☐	☐	☐
Our teacher makes outer space an interesting and relevant topic to study	☐	☐	☐	☐	☐
Learning about outer space is fun for me	☐	☐	☐	☐	☐
The labs that we have done have	☐	☐	☐	☐	☐

piqued my interest about space					
I have researched outer space topics outside of class, to learn more about what were learning in class	☐	☐	☐	☐	☐
I focus exclusively on the space labs we do in class without feeling distracted by my smartphone	☐	☐	☐	☐	☐
I use a smartphone for entertainment during science labs	☐	☐	☐	☐	☐
I use a smartphone during lab time because I feel nervous about working in groups	☐	☐	☐	☐	☐
I use a smartphone during lab time because I feel like I don't have anything to contribute to group work	☐	☐	☐	☐	☐
I use a smartphone during lab time because I am uncertain as to what I should be doing during the lab	☐	☐	☐	☐	☐
I feel confident using the scientific tools required for science labs	☐	☐	☐	☐	☐
I have a smartphone that I	☐	☐	☐	☐	☐

bring to class with me					
A smartphone can be a helpful educational tool	☐	☐	☐	☐	☐
I am more comfortable using a smartphone as a measurement tool than a traditional scientific measuring device.	☐	☐	☐	☐	☐
I use a smartphone in class to look up relevant class material	☐	☐	☐	☐	☐
I use a smartphone as a tool to complete lab activities	☐	☐	☐	☐	☐

When you have completed this survey, tear it out of the package and hand it to your teacher before proceeding with the next part of the lab.

Part 3 – Measuring Sound with a Smartphone

Check-in:

- *Have you completed Part 1 and 2 of the Lab?*
- *Have you completed Follow-up Survey #1?*

1. Download a **free** sound meter app on your smartphone (Ex. *Decibel X, Sound Meter)*
2. Ensure your ping pong balls are in the basket
3. Secure your metre stick with one end in the basket, keeping upright so that height of drop can be measured (see photo to right)
4. Position the smartphone as close to the ping pong balls as possible for optimal sound measurement
5. For each drop, note the baseline class noise level in your chart *(dB min)*
6. Drop the smaller ball from 25 cm height into the ping pong balls, and note the maximum decibels achieved during drop in your chart *(dB max).* Repeat two more times from this height, for a total of 3 tests.
7. Now, proceed to drop the small ball from 50 cm and 100cm from ground, taking note of dB min and max in your chart. Make sure to repeat each height 3 times.
8. Repeat steps 6-7 using larger ball. Note all measurements in your chart.

9. Take the time to complete Table 3 and 4, calculating dB difference for all trials, using the formula below:

dB difference = dB max – dB min (baseline)

TABLE 3: SMALL BALL TRIAL DATA AND CALCULATIONS			
Initial Height (cm)	**Test #1**	**Test #2**	**Test #3**
25	dB min = dB max = dB difference =	dB min = dB max = dB difference =	dB min = dB max = dB difference =
50	dB min = dB max = dB difference =	dB min = dB max = dB difference =	dB min = dB max = dB difference =
100	dB min = dB max = dB difference =	dB min = dB max = dB difference =	dB min = dB max = dB difference =

TABLE 4: LARGE BALL TRIAL DATA AND CALCULATIONS			
Initial Height (cm)	**Test #1**	**Test #2**	**Test #3**
25	dB min = dB max = dB difference =	dB min = dB max = dB difference =	dB min = dB max = dB difference =
50	dB min = dB max = dB difference =	dB min = dB max = dB difference =	dB min = dB max = dB difference =
100	dB min = dB max = dB difference =	dB min = dB max = dB difference =	dB min = dB max = dB difference =

Part 4 - Analysis

- Return your materials to the teacher to be sanitized
- Answer the follow up questions below

1. Describe the accuracy of your trials – were there any numbers that stood out or didn’t make sense? Can you provide an explanation for the irregularities?

2. Explain, in your own words, how this lab is related to the XENON1T Dark Matter lab.

Follow-up Survey #2

Complete only once you have completed Part 3 and 4 of the labs and before you begin Part 5

Name:

	Strongly Disagree	**Disagree**	**Unsure/ no opinion/ not relevant**	**Agree**	**Strongly Agree**
In my leisure time, I engage in topics that are related to the study of space (beyond what is in my homework)	☐	☐	☐	☐	☐
Outer space is an important topic for young people to learn about	☐	☐	☐	☐	☐
The outer space topics that we cover in class make sense to me	☐	☐	☐	☐	☐
Our teacher makes outer space an interesting and relevant topic to study	☐	☐	☐	☐	☐
Learning about outer space is fun for me	☐	☐	☐	☐	☐
The labs that we have done have piqued my interest about space	☐	☐	☐	☐	☐
I have researched outer space topics outside of class, to learn more about what were learning in class	☐	☐	☐	☐	☐
I focus exclusively on the space labs	☐	☐	☐	☐	☐

we do in class without feeling distracted by my smartphone					
I use a smartphone for entertainment during science labs	☐	☐	☐	☐	☐
I use a smartphone during lab time because I feel nervous about working in groups	☐	☐	☐	☐	☐
I use a smartphone during lab time because I feel like I don’t have anything to contribute to group work	☐	☐	☐	☐	☐
I use a smartphone during lab time because I am uncertain as to what I should be doing during the lab	☐	☐	☐	☐	☐
I feel confident using the scientific tools required for science labs	☐	☐	☐	☐	☐
I have a smartphone that I bring to class with me	☐	☐	☐	☐	☐
A smartphone can be a helpful educational tool	☐	☐	☐	☐	☐
I am more comfortable using a smartphone as a measurement tool than a traditional	☐	☐	☐	☐	☐

scientific measuring device.					
I use a smartphone in class to look up relevant class material	☐	☐	☐	☐	☐
I use a smartphone as a tool to complete lab activities	☐	☐	☐	☐	☐

When you have completed this survey, tear it out of the package and hand it to your teacher before proceeding with the next part of the lab.

Part 5 – Blind measurements/Class data

For this part of the procedure, you will be using some of the data you took earlier in the experiment and sharing with the class – but you will not be specifying whether it was a large or small ball that was dropped. The purpose here is to see, as a class, if we can guess the weight of the ball dropped based on the sound data – a blind experiment!

1. You have completed 4 data tables of data. Choose **one** of those data tables, and copy the information below from your Test #3 column:

<table>
<tr><td colspan="2">Large or small ball dropped:
Decimeter or smartphone used:
(Do not share the ball or tool used on the board – only the information below)</td></tr>
<tr><td>Initial Height (cm)</td><td>Test #3</td></tr>
<tr><td>25</td><td>dB difference =</td></tr>
<tr><td>50</td><td>dB difference =</td></tr>
<tr><td>100</td><td>dB difference =</td></tr>
</table>

2. Once you have completed your table, write the 3 dB values on the class whiteboard, but do not share what ball was dropped or the tool you measured with.
3. As more students add their information to the class data, start to complete the table below by guessing what size ball you think was dropped in their data.

Student name: What ball dropped?	Student name: What ball dropped?	Student name: What ball dropped?	Student name: What ball dropped?	Student name: What ball dropped?
Student name: What ball dropped?	Student name: What ball dropped?	Student name: What ball dropped?	Student name: What ball dropped?	Student name: What ball dropped?
Student name: What ball dropped?	Student name: What ball dropped?	Student name: What ball dropped?	Student name: What ball dropped?	Student name: What ball dropped?
Student name: What ball dropped?	Student name: What ball dropped?	Student name: What ball dropped?	Student name: What ball dropped?	Student name: What ball dropped?
Student name: What ball dropped?	Student name: What ball dropped?	Student name: What ball dropped?	Student name: What ball dropped?	Student name: What ball dropped?

4. As a class, once everyone has provided their info on the whiteboard, we will be discussing as a class our hypotheses for what ball was dropped.

Part 6 – Final Analysis

1. Describe how you made your guesses of other students' data in Part 5. What information was important to help you decide the size of ball that was dropped?
2. Describe the accuracy of your guesses for the Part 5 of this lab.
3. Do you think there were any sources of error for this lab, which would have made guessing correctly difficult? Explain.
4. What were the biggest challenges you faced during this lab? What did you do to overcome these challenges?

Follow-up Survey #3

Complete only once you have completed Part 3 of the lab

In this lab, you used both a decimeter and a smartphone to measure sound. Which tool did you prefer using and why? (Please answer in as much detail as possible)

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