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Using an AR Drone Lab in a Secondary Education Classroom to Promote Quantitative Research

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1. Introduction

In recent years, science, technology, engineering, and math (STEM) educators have sought innovative ways for integrating technology in teaching and learning to engage and build the interest of secondary school students in STEM disciplines as well as to capture their imagination about STEM careers. Recent technological advancements have allowed design, development, and commercialization of low-cost mini unmanned aerial vehicles (MUAV) that offer a novel and ideal platform to support STEM disciplines in high school classrooms.[1] This paper focuses on one illustrative example wherein four sections of a 9th grade quantitative research course, consisting of 25 to 30 students each, were engaged by a graduate researcher through an AR Parrot 2.0 (see Figure 1) MUAV-based lab activity, which considered the research question "How fast does the AR Drone fly?" Within the framework of a hands-on lab, the students designed a MUAV-based controlled experiment, collected their own data, used the collected data to formulate an understanding of the physics, and applied relevant mathematics to reach conclusions. The graduate researcher integrated and examined an array of motivational factors in the lesson, including the embodiment of quantitative research principles, critical thinking about real-world scenarios, ownership of experimental procedure and outcome, and gamification wherein students used a video game controller to pilot the MUAV in the experiment. Finally, the MUAV lab targeted the special learning needs of students with autism spectrum disorders (ASD) who composed of 12% of the student body in the school.

Figure 1: AR Parrot 2.0

This effort integrated a series of learning elements unique to the structure of the lesson, e.g., a situated cognition model[2,3] to frame the experimental activity, a project-based learning[4] (PBL) structure in a lab environment, and a social constructivist[5,6] approach to bridge the gap between the scientist and the classroom. Specifically, the situated cognition model[2,3] was incorporated by the graduate researcher posing as a member of a university lab that conducts Department of Defense (DoD) sponsored research. Students were informed that the university lab was preparing to bid on a high-dollar classified MUAV project with a DoD agency and the lab needed students' support in performing preliminary research to generate experimentally validated data for the proposal. This approach produced a contagious excitement and ownership because many students in sections following earlier introductory sections knew what to expect; their peers from earlier sections had shared the idea outside of class. Furthermore, hands-on interactions embedded in PBL[4] allowed students to "do something" to "learn about something," instead of the usual classroom teaching with singular focus on "learn about something." At the start of the MUAV lesson, students drew names out of a hat to choose between four possible roles: piloting the MUAV, timing MUAV flight to measure its ground speed over a set number of parking spaces located behind the school, recording data, and making experimental observations to explore sources of error. In a class meeting prior to the day of the experiment, students convened in their respective groups to discuss how they might perform their roles to achieve the best possible results. During post-experiment reporting, students provided answers to the question "How fast does the AR Drone fly?," culminating in a research presentation and a formal lab report to model activities used in post-secondary level labs.[7] Within the experiment, a social constructivist approach allowed students to connect past and present experiences in their lives with the phenomena they observed in the scientific experiment. Research questions were posed in a self-deprecating way with a supposed hesitation of particular answers to provide a fuller understanding of the physical world as the students confirmed or rejected their own prior assumptions.

Following the lesson, a post assessment was conducted wherein students were given a survey to indicate other types of experiments they might want to conduct using a MUAV. While some of the ideas conveyed in the survey are not deemed feasible, others provide an insight into how future teachers might design a MUAV lesson plan differently to better capture the interests of the students.

2. Motivation

The AR Drone lab was integrated into a quantitative research class for 9th grade students. Below we discuss how the AR Drone lab design supports the goals of quantitative research in education and how it promotes mastery of scientific reasoning, which is a fundamental concept in STEM education. Scientific reasoning requires understanding and application of both qualitative and quantitative research methods that are offered as two separate required courses in the high school where the AR Drone lab was implemented. While qualitative research is primarily concerned with giving detailed descriptions of particular events or process to discover new behaviors or patterns, quantitative research focuses on developing and testing hypotheses and constructing models that explain such behavior or pattern.[8]

Quantitative research has been defined as[9] "Explaining phenomena by collecting numerical data that are analyzed using mathematically based methods (in particular statistics)." This formal definition of quantitative research served as the foundational motivation in designing the AR Drone lab and a myriad of other classroom activities including lessons on oil spill cleanup, the food processing industry, climate change, HIV prevention, etc. While some lessons and activities required students to analyze pre-collected scientific data from academic sources, others, such as the AR Drone lab, engaged students to collect their own experimental data. After understanding the meaning of data, the students applied relevant mathematical methods to support their arguments. Through basic numerical (addition, subtraction, multiplication, and division) and statistical (average, median, mode, and range) calculations, the students grasped how, why, and when to use a particular mathematical tool to formulate a conclusion.

Quantitative research can be further categorized as: 1) experimental or non-experimental research, 2) theoretical or practical research, and 3) descriptive research.[8] As delineated below, the AR Drone lab was designed to embody all of these characteristics to give the students a fuller understanding of quantitative research. First, the students were guided to design an experiment for testing the ground speed of the AR Drone. Moreover, they used school computers to research AR Drone specifications, such as battery life and control features. Second, before experimenting with the AR Drone, students were taught the theory behind the ground speed and the calculation procedure using the distance traveled and flying time. Students learned to make judgment calls based on both practicality and experimental requirements. For example, when posed with an experimental design question, one student suggested testing the ground speed of the AR Drone by flying it down a street outside the school while another student argued that operating the AR Drone on a busy street will be impractical and pose a danger to public safety. Consequently, students mutually agreed that an empty parking lot behind the school can serve as a feasible test-range. Third, a group of students comprising roughly half of each class were assigned the role of observers in the experiment. Each of the observers maintained a notebook to record and describe sources of experimental error and other relevant information. Although descriptive research of aforementioned nature can be construed as qualitative research, such overlap is common and necessary in designing a successful experiment. Moreover, while working with numerical data, it is vital to include qualitative assessment, with which high school students have greater familiarity, for bridging the link between the two areas to use evidence to support a claim.

As recently reported,[7] educators have employed the AR Drone to implement a MUAV experiment, *QuadLab*, in a post-secondary laboratory learning environment. The success of AR

Drone as an educational platform at the post-secondary level illustrates its potential applicability in high school education to reach out to younger students. Similar to the broad appeal of mobile robotics platforms to students at all levels, the novelty of MUAVs can be used as a hook to engage high school students in STEM learning. Whereas the post-secondary MUAV lab focuses on topics such as communication, robotic design, and automation and control, this high school level AR Drone lab focuses on quantitative thinking, experimental design, project-based learning,[10] and common core math standards.[11]

Similar to Ref. 7, the AR Drone was selected due to its ease of use, low cost, safety, and reliability. The AR Drone costs ~$300, it can be readily purchased off-the-shelf at mainstream retailer outlets, there is a foam surround to shield foreign objects from the rotors, and open source software for control via a joystick gaming controller is readily available, easy to install, and allows reliable operation of the AR Drone. A down-facing ultrasonic sensor that detects ground distance allows the AR Drone to be easily landed with the click of a single button on the gaming controller, regardless of the flying speed or height. This ease of operation allows student "pilots" to easily complete experimental trials while staying engaged and feeling in control.

The quantitative research methods course provided motivation to engage students in gaining a deeper grounding in error and how it affects the AR Drone lab experiment. While Ref. 7 used embedded technology of the AR Drone software development kit to collect data such as flight time, we opted to assign students roles as "flight timers" with stop watches. In addition to keeping students more engaged, this purposefully introduced a source of error that the students could later analyze using statistics.

The educational QuadLab[7] introduced a custom graphical user interface (GUI) on a computer for students to control the MUAV. While such an approach is suitable at the post-secondary education level, we concluded that the complexities entailed in interacting with and interpreting the multiple buttons and graphs of the GUI might confuse students at the secondary education level. To circumvent this problem and to further engage the high school students, we were motivated to employ a method of gamification[12] in operating the MUAV.

The AR Drone lab was an integrated classroom, a setting in which general education and special education peers worked and learned together. Therefore the lab was filled with diverse learners with varied skill sets, learning styles, strengths, and challenges. In particular, a subset of this class was composed of students diagnosed with ASD. Gamified activities can be particularly challenging since the criteria for ASD diagnosis includes clinically significant, persistent deficits in social communication and interactions across contexts.[13] However, the AR Drone lab taps into areas of students' special interest, thus increasing the likelihood of social engagement. In one case, researchers framed a summer camp around robotics to decrease social anxiety among adolescents with ASD.[14] Research has shown that a substantial percentage of students with ASD develop deep interests in STEM topics, and have abilities that are well-suited to STEM coursework and careers, e.g., the ability to engage in systems thinking, to concentrate for long periods on complex topics, and to pay close attention to detail.[15,16]

Students with ASD, even those who have interests in academic topics, can fall off the pathway to professional careers because successfully navigating the process of preparing for and succeeding in college and careers requires more than academic ability.[17] Skills such as social communication, organization, and collaboration are some of the abilities necessary to succeed at the post-secondary level. It is essential to build and practice these skills early on because postsecondary success is dependent on the habits of mind that students develop, the academic courses they take, and the extracurricular activities they pursue from the beginning of high school.[18] Extracurricular activities, specifically participation in sports teams, provide ample opportunity to develop collaborative and social communication skills. However, participation in sports tend to require motor control and several studies have reported on the motor control difficulties in children with ASD, including how proprioceptive difficulties among children with ASD may contribute to decreased motor planning and to disruptive behaviors that negatively affect their participation in daily tasks.[19] Thus, participation in STEM based gamified activities can serve as an alternative opportunity to develop collaborative and social communication skills. The AR Drone lab affords students with ASD a chance to participate in an activity based on their interest while also providing an opportunity to develop the critical social skills for future success.

3. Learning Elements

3.1. Project-Based Learning in a Laboratory Environment

A widely used pedagogical tool in STEM classrooms is PBL.[4] One key attribute of PBL is "doing something" to "learn about something," instead of the usual classroom teaching with singular focus on "learning about something." This interactive technique allows teachers to capture students' attention by finding an element of fun in the task they are learning.

> "In every job that must be done, there is an element of fun.
> You find the fun and – SNAP – the job's a game." – *Mary Poppins*

"Doing something" is commonly associated with activity, enjoyment, and engagement. Effectively incorporating this into the STEM classroom through PBL promotes learning ideals so that students may successfully collect numerical data while doing something they enjoy to achieve lesson plan goals in a quantitative research class. Moursund[4] highlights six ways in which PBL may be analyzed from a student's point of view. We can directly apply these to evaluate the constituents of the AR Drone lesson.

1. *Learner centered, intrinsically motivating:* Before conducting the experiment, the students drew names out of a hat for selecting four possible roles: piloting the drone, timing the drone flight to measure its ground speed over a set number of parking spaces located behind the school, recording data, and making experimental observations to explore sources of error. As learners performed these key roles, they controlled the outcome of the experiment. Learners were given an opportunity to critique the suggested initial parameters for experiment provided by the graduate researcher, such as how many parking spaces the AR Drone would fly over and when the timers would start and stop the timing: would they start the timing when the AR Drone begins to hover or when it begins to fly forward? This ownership of the experimental process centers the focus on the learners by allowing them to modify, or "tweak" their role. For reasons previously stated, gamification of this experiment was intrinsically motivating as was the novelty of controlling a MUAV.

2. *Collaboration and cooperative learning:* On the day before the experiment, the students were divided in the groups of their respective role and given ample time in class to meet and discuss how they might approach the experiment as a whole. Likewise, they had ~10 minutes to exchange thoughts at the parking lot just prior to beginning the experiment when their excitement was building. In between each trial, the graduate researcher instructed each group to think critically out loud about the previous trial and how their role affected it. As a result the students cooperated to learn how the best conduct the experiment.

3. *Incremental and continual improvement:* Each of the five pilots in his/her class section was given the opportunity to fly the drone for at least two trials. The pilots increased their flying speed average from 4.3 ft/s to 4.7 ft/s from the first to the second trial. Furthermore, the standard deviation of the time recorded decreased from 2.4 seconds to 1.2 seconds, showing incremental improvement of accuracy. This can be attributed to both a refinement of piloting skills and better accuracy of time data collection by paying closer attention to starting and stopping the watch. Those who observed the experiment and sought out error sources continually improved by identifying patterns throughout the trials, such as a relatively steady tailwind that caused the AR Drone to fly faster than it otherwise would.

4. *Actively engaged students:* Team roles emphasized necessary participation in the experiment, requiring the students to stay focused and engaged. Rather than giving direct instructions to the students, the graduate researcher acted as a "guide on the side" rather than a "sage on the stage." Because the graduate researcher took this secondary mentoring role, the students were given authority to make judgment calls and act independently. With the exception of one student who purposefully crashed the AR Drone while piloting, everyone responded well to this form of leadership.

5. *Product, presentation, or performance:* Following the AR Drone testing, each group of students was required to make a presentation based on their experience. Each group had to assess their role and each individual team member talked about his/her experience within the group. They discussed possible sources of errors and the difficulties they encountered trying to perform each test as reliably as possible. For example, pilots mutually agreed on the presence of wind and how it affected their control. Each presentation was assessed by the teachers of the class and the graduate researcher and graded based on the students' understanding, communication, and performance within the group.

6. *Challenging, with a focus on higher-order skills:* Plunging the students into a research role while integrating gamification techniques and the novelty of a MUAV provided a challenge that they could readily engage in. It drove growth of higher order skills, requiring them to transfer knowledge from diverse areas of interest such as gaming to scientific research. They learned to make judgment calls, identified errors that affected results, observed novel scientific testing, and used fine muscle control flying the MUAV precisely and accurately. For example, students timing the experiment made the judgment call on whether to start time before takeoff or when the AR Drone crossed the starting line. Data driven post-experimental analysis with statistical calculations provided a learning opportunity for quantitative analysis, a challenge and essential step in scientific thinking.

3.1.1. Do Real Work, Not Homework

It is crucial to make a distinction between *learning about, learning, and learning to be* and how this affects secondary education.[20] Although the latter distinction prominently resides in art education, at the secondary education level, science educators have a more difficult time than art educators to teach students *to be* scientists and to break away from *learning about* conundrum.[20] Instead of how art students *learn to be* artists through the reaction of observers' critique of their work, students in science education frequently *learn about* science because the standard medium of criticism is a single grade on an assignment. However, by creating authentic learning tasks, science educators can teach students to be scientists by incorporating real work: real-world relevant assignments, ill-defined problems, sustained investigation, collaboration, and reflection. The AR Drone lab targeted all of these real work elements with its inherent real-world importance in technology, ill-defined experimental process, sustained investigation of error sources, and continuous collaboration and reflection between teams. Simultaneously, it promoted the three categories within quantitative research through this real work scenario: actual experimental design and setup, theoretical calculations of ground speed from distance and time, and descriptive analysis of a real-world scenario.

Within the "real work" learning process, it is essential to account for how the Net Generation learns.[21] The technological savvy of current generation of secondary school students provides an excellent opportunity to teach real work in a classroom with computer-aided lessons. In the AR Drone lab students were given multiple opportunities to use the Internet and Microsoft Office to perform research, tabulate data, and design presentations. These are prime real-work examples that professionals encounter on a regular basis as a medium for research, discovery, understanding, and communication.

3.1.2. Laboratory Framework

To better prepare the ninth-grade students for college, the AR Drone experiment was integrated into a laboratory and targeted areas that students may find problematic in post-secondary education. Specifically, when working on a college-level lab, students must think intuitively, follow directions carefully, divide work among peers, consider all possible solutions, and provide quantitative answers to support their claims.

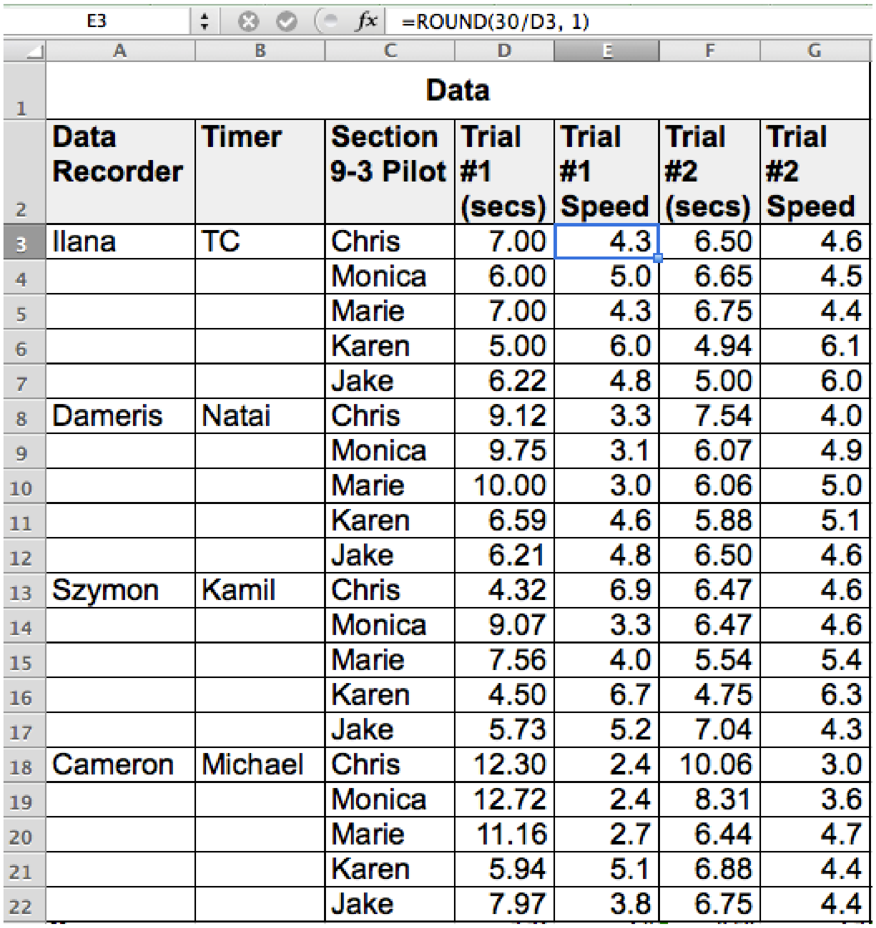
In the AR Drone lab, the students were first introduced to the experiment through exploratory (rather than confirmatory) discussion. They were asked the question "*How fast does the AR Drone fly?*" The exploratory nature of discussion encouraged out-of-the-box thinking of ways to approach the experiment. Next, they were asked to design the experiment with guidance to determine flight speed quantitatively. For example, the students collectively mapped out areas possible to test the AR Drone flight speed, deciding on the parking lot behind the school. Then, they chose to fly the AR Drone for a length of 30 feet, roughly equal to three parking spaces—a convenient and sensible decision given test location. In making this quantitative decision, students were taught about scaling factors and how the size of the vehicle in question relates to the testing area. Moreover, they chose units in which to measure experimental data, e.g. time in seconds and distance in feet, with the final speed calculation in units of feet per second. This mapped out a clear set of directions for students to follow while retaining ownership of their ideas.

By drawing names out of a hat to determine their role in the experiment, the students successfully and fairly divided work, forming teams of various roles. They chose five pilots, five timers, five data recorders and 10-15 observers per class. This division of roles supported quantitative research goals by requiring students to make numerical decisions about the setup of a controlled experiment. Each pilot flew the drone two flights across the parking spaces using the video game joystick controller to take off, go forward, and land. The timers measured the flight time using a stopwatch and the data recorders wrote down the flight time in a notebook as well as the name of the pilot corresponding to each time. Meanwhile, the 10-15 observers worked to analyze experimental conditions and look for sources of error. Like the data recorders, the observers also recorded the pilot's name so that error conditions could be correlated with flight times in analysis.

The data analysis was completed quantitatively in Microsoft Excel while assignments were given to explain experimental thought process and reasoning. Students recalled their work and wrote down all steps of the experimental procedure. Next they explained why they chose the location of the experiment and the flight length of 30 feet. The speed of the MUAV was calculated theoretically with the following equation, with units of feet and seconds for distance and time, respectively.

$$\text{Speed}=\frac{\text{Distance}}{\text{Time}}$$

Students entered the data into Excel and learned how to properly round numbers to the correct significant figure. Time was recorded to the hundredth of a second but distance was measured to the nearest foot. For the flight length of 30 feet, the speed was rounded to one significant figure. To encourage teamwork and speed up the process of data entry, classes were separated into groups of three to five students per computer. The graduate researcher taught individual groups to make calculations dependent on various cells by using the function editor in Microsoft Excel. Figure 2 shows data recorded and timed for all pilots by four of five data recorders and timers.



E3 =ROUND(30/D3, 1)

Data

Data Recorder	Timer	Section 9-3 Pilot	Trial #1 (secs)	Trial #1 Speed	Trial #2 (secs)	Trial #2 Speed
Ilana	TC	Chris	7.00	4.3	6.50	4.6
		Monica	6.00	5.0	6.65	4.5
		Marie	7.00	4.3	6.75	4.4
		Karen	5.00	6.0	4.94	6.1
		Jake	6.22	4.8	5.00	6.0
Dameris	Natai	Chris	9.12	3.3	7.54	4.0
		Monica	9.75	3.1	6.07	4.9
		Marie	10.00	3.0	6.06	5.0
		Karen	6.59	4.6	5.88	5.1
		Jake	6.21	4.8	6.50	4.6
Szymon	Kamil	Chris	4.32	6.9	6.47	4.6
		Monica	9.07	3.3	6.47	4.6
		Marie	7.56	4.0	5.54	5.4
		Karen	4.50	6.7	4.75	6.3
		Jake	5.73	5.2	7.04	4.3
Cameron	Michael	Chris	12.30	2.4	10.06	3.0
		Monica	12.72	2.4	8.31	3.6
		Marie	11.16	2.7	6.44	4.7
		Karen	5.94	5.1	6.88	4.4
		Jake	7.97	3.8	6.75	4.4

Figure 2: Screenshot of student group work: using the function editor

Students explored various graph types such as line graphs, column graphs, pie charts, scatter plots, and various other subsets that fell within these graphing categories. In graphing ground speed from multiple trials, students were shown why a pie chart was not acceptable (data was not measured as a percentage), and how other choices could be justified. Many students chose a 2-D clustered column type graph, and Figure 3 is an example taken from a student's lab report.

Following the plot of individual trials, students learned statistical concepts and numerical calculations of mean, median, mode, range, and standard deviation. The graduate researcher underscored the importance of these calculations in college-level lab work and other professions outside of the STEM fields. Many of the students learned the concepts and calculations for the first time and the graduate researcher and quantitative research teachers spent two full class periods teaching it to highlight the importance. Figure 4 shows a screenshot of statistical calculations performed using Microsoft Excel.

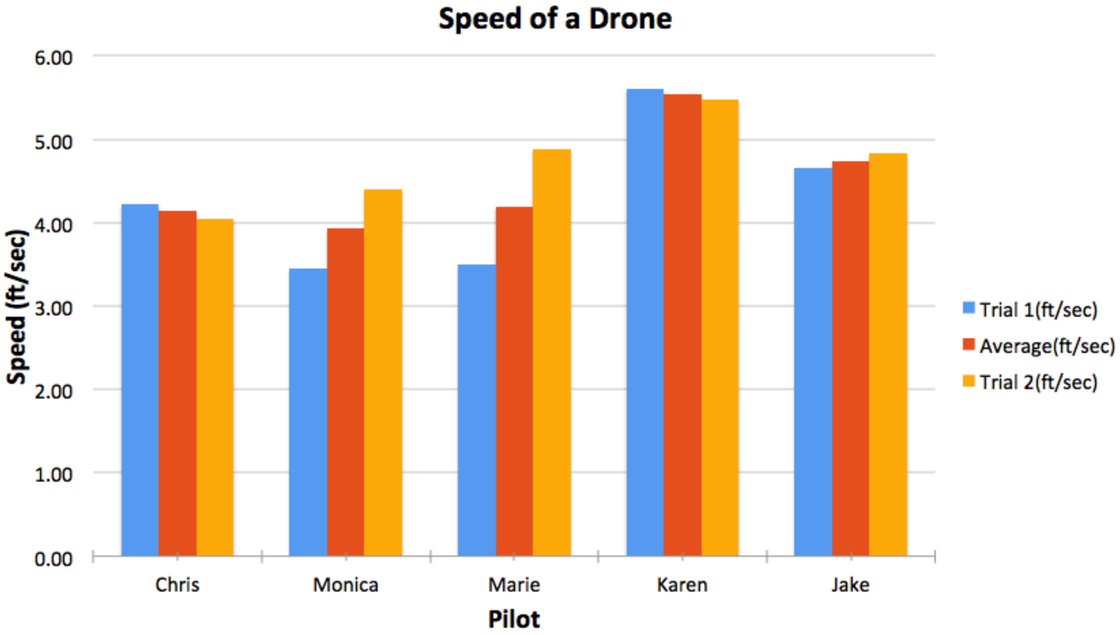
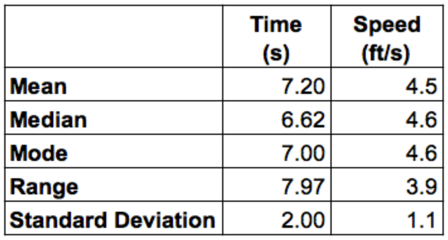


Figure 3: 2-D clustered column graph showing MUAV speed



	Time (s)	**Speed (ft/s)**
Mean	7.20	4.5
Median	6.62	4.6
Mode	7.00	4.6
Range	7.97	3.9
Standard Deviation	2.00	1.1

Figure 4: Screenshot of student group work: statistical calculations

There was at least one trial (out of ten) per class section where a pilot became confused with the game controller and flew the MUAV considerably off course, increasing the "normal" flight time. As seen in Figure 3, both Monica and Marie had difficulty flying the MUAV during their first flight trial. In one case a large gust of wind blew the MUAV more than a full parking space laterally, causing an increase in its flight time. Because the data recorder and observer information was correlated with the flight time via pilot name and trial number, the students worked as a team to identify these outlier samples and provide explanations based on quantitative data. For both examples, some students removed the data from their lab report while others included it, highlighting the learning element of using evidence to support a claim. Students documented this process in personal notebooks.

Through data-driven experimentation and analysis, students provided answers to the question of "*How fast does the AR Drone fly*?," culminating in a formal lab report modeling those used in college level laboratories. They assembled this report using a standard format with the following sections: *Introduction, Procedure, Results, Discussion,* and *Conclusion*. It was expected that students would be intimidated by the idea of writing a formal lab report in 9th grade. To ease this intimidation, the report was designed so that students had comprehensive knowledge of all information necessary to complete the report before it was assigned. Students used assignments they had previously completed such as the procedure, the data, and elements of the discussion to assist in writing the report.

3.2. Gamification: An Appeal to Students with ASD

The AR Drone lab worked toward the strengths of students with ASD due to the nature of the skills needed and the use of equipment that mimics video game controllers. Specifically, students with ASD tend to be adept at piloting a drone due to the detail-oriented nature of the task. It has been shown that technology can create a natural and powerful motivator for students on the spectrum.[14] Thus, we used the AR Drone lab for encouraging students with ASD to engage socially through shared interests, building upon their strengths and working toward a common goal. By utilizing a custom video game controller to operate the MUAV, we instructed students to fly from start to end as quickly as possible. A digital LCD screen affixed to the controller displayed relative velocities in three directions: up/down, left/right, and back/forth. Figure 5 shows this in addition to highlighting the novel wireless control board that communicated between the AR Drone and a laptop via Wi-Fi.

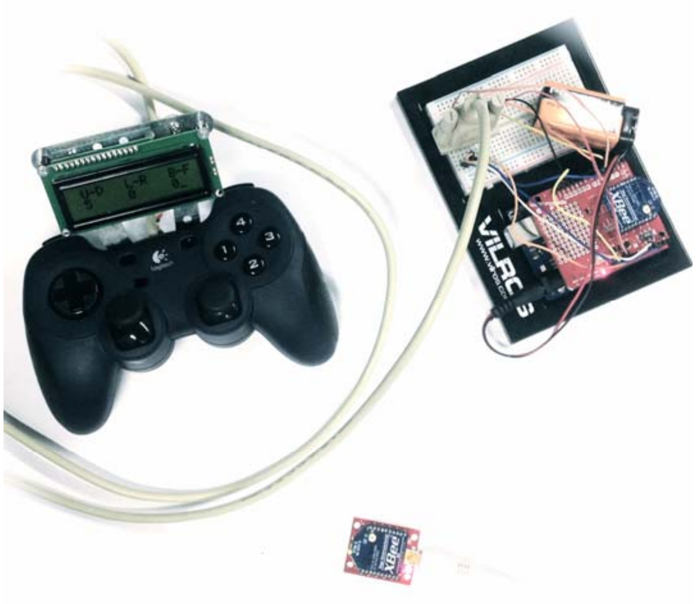


Figure 5: MUAV controller highlighting aspects of gamification

In recent years, many educators have used gamification methods to engage students in a variety of disciplines.[22–25] By thinking like a gamer, the educator can use digital technology to make seemingly mundane tasks more enjoyable.[12] Coined "the game layer," overlaying game mechanics to learning tasks makes them more compelling, thrilling, and even consequential. For years, high performing students have participated in gamified activities such as spelling bees and math competitions. However, for a vast majority of students, extracurricular activities and sports are frequently the only means of gaming at school. Yet, it has become increasingly feasible to integrate competition and gaming elements into the academic setting for all levels. For example, with the AR Drone lab, students access instantaneous information about flight time to fly the AR Drone as fast as possible. This creates a competitive environment, pitting pilot against pilot, while achieving experimental goals of measuring AR Drone flight speed. Furthermore, the video game controller appealed to students with experience in playing video games for entertainment purposes. By appealing to students of diverse academic level and skill sets, this multilayered gamification technique promoted peer-to-peer learning.

3.3. Situated Cognition and Social Constructivism

Traditional learning methods focus on teaching students the tools of a particular discipline and often avoid details regarding the culture within that discipline.[2] Although this conceivably links necessary content to the classroom, the attraction of that culture to promote learning may be lost in translation. We posit that, by ignoring the situated nature of cognition, education defeats its own goal of providing usable, robust knowledge. Conversely, we argue that, approaches that embed learning in activity and make deliberate use of the social and physical context are more in line with the understanding of learning and cognition that is emerging from research.[2]

To pave a path for effective learning, we implemented a laboratory model of situated cognition to engage students. Upon introducing the experiment to secondary school students, the graduate research posed as a member of a university lab that conducts DoD sponsored research. This immersed the students into the research disciple by linking them directly to a fascinating culture within a lucrative field. Students were informed that the university lab was preparing to bid on a high-dollar classified MUAV project with a DoD agency and the lab needed students' support in performing preliminary research to generate experimentally validated data for the proposal. Successful flight of the MUAV in military applications is highly dependent on flight speed. Students were instructed to assist the graduate researcher in this speed testing that can help facilitate university lab's bid for the DoD funding. By transporting the minds of the students into a situation where they felt needed, the graduate researcher intended to arouse their interests and generate a contagious excitement, motivating students to excel in the MUAV lab experiment.

3.3.1 Social Constructivism

The influence of Jean Piaget's social constructivist ideas[5] into educational intentionality is undoubtedly widespread.[6] In the context of education, "…, as constructivism implies that knowledge is always knowledge that the person constructs, it has prompted the development of didactic situations which stress the need to encourage greater participation by students in their appropriation of scholarly knowledge." Social constructivism paves a pathway for students to advance their opinions to justified beliefs by thorough questioning of fundamental principles and reinterpretation of knowledge according to the personal experiences of the student.

The goal of a science-based class is to promote a fuller understanding of the physical world surrounding us. Scientists frequently present their ideas of the physical world in verbal forms that accurately articulate a concept to a peer, yet such a method can alienate the audience of a secondary education classroom. The concept of social constructivism is essential in bridging the gap between the scientist and the classroom. When students start to learn new ideas, they must first understand the problem and what is means to them before they can attempt to comprehend the scientific theory.[26] According to Fosnot,[26] this barrier to knowledge development is not new—over one hundred years ago, John Dewey emphasized the importance of how a student's knowledge must grow from experience. Constructing a knowledgebase requires that the students link past and present experiences in their lives in connection with the phenomena they observe in scientific experimentation. Once the teacher succeeds in coupling these with scientific theory, a fuller understanding of the physical world is reached.

A key element in successful constructivist teaching is the formulation of questions during experimentation when the student is interacting with the physical world. In addition to questioning the students, the teacher may pose the question in a self-deprecating way, so the students may use the scientific experiment to confirm the teacher's supposed hesitation of a particular assumption or answer.[26] This allows the students to construct proof of a physical concept based on a foundation of their own experience, promoting pride in scientific comprehension through confirmation of one's solution to a question.

Previously, many authors have applied constructivism techniques to the use of robotics in education.[7,27,28,29] Specifically, Refs. 27—29, integrate robotics into pedagogies to teach engineering and science through design and construction of various Lego robotic systems. Moreover, Ref. 7 applied constructivism at a college level to program controls through the modification of AR Drone control on a computer. In this paper, we combine constructivist method executions of Refs. 7, 27—29, culminating in a pedagogy that allows students to thoroughly question fundamental principles and reinterpret knowledge according to the personal experience of flying and testing an AR Drone with their own hands.

3.3.2. Research-Based Teaching

Developing a strategy to link research to teaching permits students to ask significant questions about the task at hand.[30] Teachers commonly integrate research methods into curricula, such as essays in the liberal arts and lab experiments in the sciences, but students are frequently unaware of the research connection. Thus, it is necessary to change the language used when integrating research into teaching. Our situated cognition model in the AR Drone lab did precisely this: by explaining to students that their work contributed to research in a novel field through quantitative analysis, they felt compelled to learn and increase their classroom participation.

Within research-based teaching, the graduate researcher carefully used pedagogic inquiry to guide the students through the experiment. Raising questions and debate in this context not only promotes student learning of the practice, but also teacher learning.[30] This gave both the graduate researcher and the quantitative research teachers better knowledge of the AR Drone, enhancing their own future discussion with a class or in a research setting. For example, the graduate researcher posed the question "How can the AR Drone detect the ground below it when it lands?" After a minute of pondering, one student correctly answered that an ultrasonic distance sensor facing downward relays a signal to the AR Drone control system. This question not only informed the quantitative research teachers about the answer, but also prompted the graduate researcher to explore cases where the sensor might relay an erroneous signal.

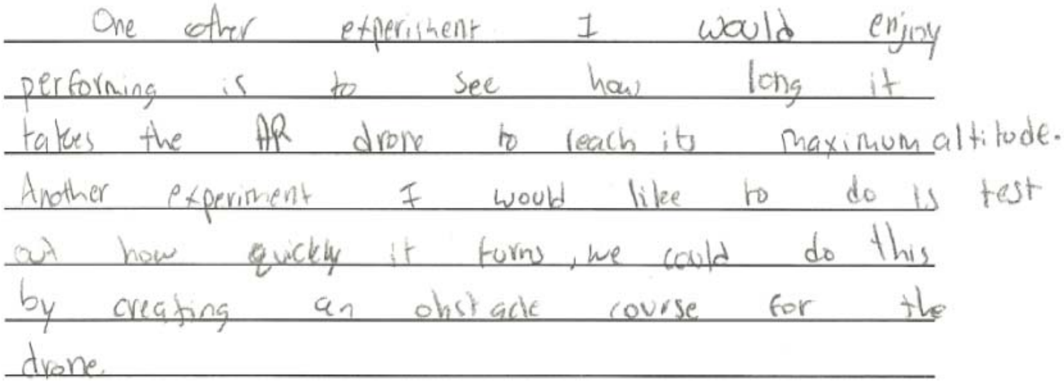
4. School Setting

The AR Drone experiment was implemented with four 9th grade classes of 25-30 students. All four classes completed the AR Drone experiment, analysis, and presentation simultaneously. The students were from an ethnically diverse school in an inner-city school from Brooklyn, NY. The following table presents further demographic information of the school.

Enrollment	387, grades 9-12
Student Demographics	12% Asian, 25% Black, 29% Hispanic, 29% White
English Language Learners	1%
Students with Special Needs	12%

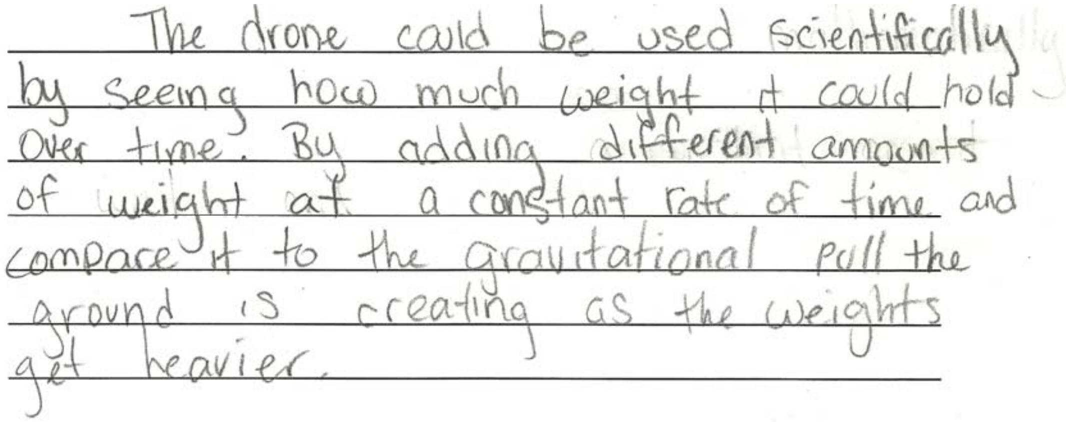
5. Assessment

While some lessons in STEM curriculum may be easily assessed with pre-/post-tests, they provide a limited evaluation of students' knowledge. Moreover, this type of assessment may be confounded when introducing entirely new technological tools. Ferdig[31] offers three criteria to evaluate performance in such a situation: content learning outcome, appropriate uses of technologies, and qualitative and observational data of social and emotional outcomes. The content learning outcome was assessed involving the three categories of quantitative research: experimental research, theoretical or practical research, and descriptive research.[8] This was completed primarily by an open-ended survey question with the intention of finding what interested students the most in the lab and how to explore further ways for teachers to conduct a similar lab in a high school setting. On a single sheet of paper, we asked each student the following question: *List at least (1) other types of experiments you would enjoy performing using the AR Drone in your high school*. We expected this would allow students to recollect the significance of their research while exploring new pathways of quantitative analysis. The following four examples of student responses are accompanied with explanations for how students were challenged.



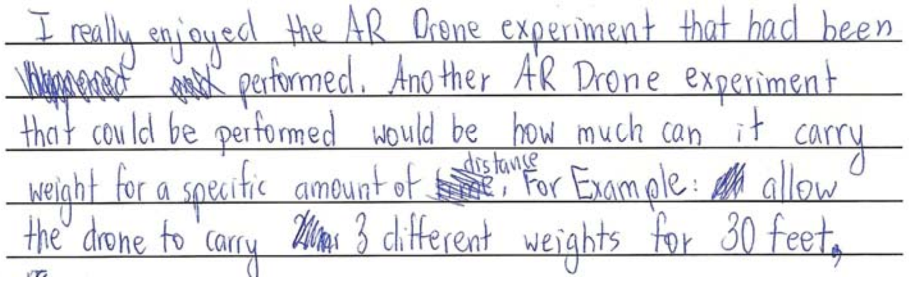
One other experishent I would enjoy performing is to see how long it takes the AR drone to reach its maximum altitude. Another experiment I would likee to do is test out how quickly it turns, we could do this by creating an obstacle course for the drone.

Clearly, this student thought about the experimental procedure and considered other future work that a scientist might perform to test the AR Drone. In addition to horizontal ground speed on a straight path, the student was challenged to consider other movements including vertical velocity and turning. The student gives insight to how this might be accomplished, such as creating an experiment with an obstacle course to measure turning speed.



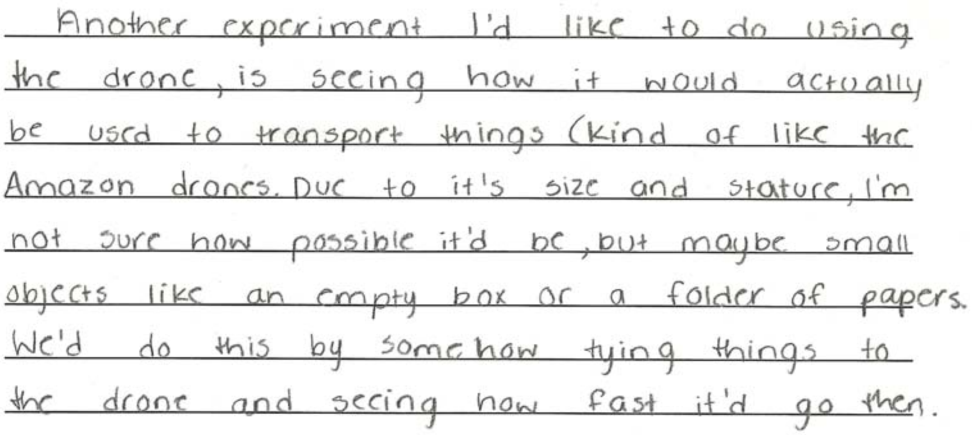
The drone could be used scientifically by seeing how much weight it could hold over time. By adding different amounts of weight at a constant rate of time and compare it to the gravitational pull the ground is creating as the weights get heavier.

The most common response about a further testing method was to add weight for future research. This student considered multiple elements of theoretical research in controlled experiments. In modeling common physics problems, a free body diagram is constructed to balance forces and moments. Previous to this diagram, it is necessary to understand how gravity affects the model: this student shows a conceptual understanding of how gravity relates to the weight that a MUAV can carry. Moreover, the student considers controlling the dynamics of the experiment by holding the rate of adding weight constant.



I really enjoyed the AR Drone experiment that had been ~~happened~~ ~~and~~ performed. Another AR Drone experiment that could be performed would be how much can it carry weight for a specific amount of ~~time~~ distance. For Example: allow the drone to carry 3 different weights for 30 feet.

Although the idea of adding weight is similar to the previous response, the difference is the method of experimental testing. Instead of adding weight at a constant time rate while the MUAV hovers, this student considers testing how far of a distance the MUAV can fly while carrying the weight. Various scientific terms were introduced throughout the lab; for example, students were taught how to correctly use units of speed, time, and distance in a theoretical relationship. This student demonstrates a clear understanding of this challenge. It can be inferred that the student understood feasibility considerations because of the suggestion to keep the flying distance at 30 feet.



Another experiment I'd like to do using the drone, is seeing how it would actually be used to transport things (kind of like the Amazon drones. Due to it's size and stature, I'm not sure how possible it'd be, but maybe small objects like an empty box or a folder of papers. We'd do this by somehow tying things to the drone and seeing how fast it'd go then.

In addition to describing another possible research avenue, this student is concerned with the feasibility of testing MUAVs with weight: an important variable. The graduate researcher observed many students' interests in Amazon's new idea of delivering packages using MUAV technology. Furthermore, others were intrigued from Harry Potter series, which features an owl that carries packages. These key motivators from preconceived interests may be used as tools in an improved model of situated cognition.

To support future iteration and implementation, the following list is comprised from students' various other ideas regarding experimentation. This includes testing in different environments, measuring different lateral ground speeds at various heights, measuring battery life in relation to flying distance, perfecting the prior ground speed experiment with revised experimental conditions, using the MUAV to take photos/video, comparing the piloting ability of those who play video games versus those that don't, observing people's reactions when they see the drone and interviewing them about it, testing the wireless signal range, among others.

In addition to the MUAV technology, other analytic tools such as Microsoft Excel were considered as the teachers and graduate research assessed the students' appropriate use of such technologies. Although the lab report was a large fraction of semester grades, it would be inappropriate to use individual grades to assess how the students learned. The lab report was the first of its kind that the students had completed, and it is sufficient to conclude that we were successful by introducing a standard college-level lab report to prepare students for the next step in their academic career. While groups completed their lab assignments leading to the report, the graduate researcher and teachers worked with them individually by making inquiries about their comprehension. For example, the graduate researcher asked individual students within the groups to show that they could use the Microsoft Excel function editor without the help of their peers. If the student was unable, the graduate researcher walked them through the process until they felt confident in performing the task. This form of inquiry-based individual feedback allowed teachers and the graduate researcher to confirm the student's grasp on material that was unprecedented at multiple levels, from the structure of a lab report to the piloting of a MUAV with a video-game type controller.

Regarding the qualitative and observational data of social and emotional outcomes, the graduate researcher assessed multiple facets of the learning elements. In assessing the situated cognition model of posing the experiment in the context of a DoD sponsored project, the graduate researcher noted an overwhelmingly positive response. The students' interest was immediately aroused and the graduate researcher was flooded with questions about the scenario. Furthermore, some students were so excited about their ability to help with the MUAV research that they informed peers in other classes, who entered the later class knowing what to expect about the experiment. The generation of contagious excitement and ownership showed the success of the situated cognition model and the importance of using the social and physical context of the DoD sponsored project.

The aesthetic of the prototyping board, the exposed microcontroller system, and wireless signaling significantly contributed to student's excitement. From a constructivist perspective, this was successful because it invoked previous ideas of electrical circuits and led the students to question the function of various components. For example, the graduate researcher pointed to the small circuit board at the bottom of Figure 5 and asked a group of students its purpose, acting as if he was unsure. One student correctly responded it was a wireless transmitter, observing its isolation from the other units and LED lights on two wireless transceivers blinking synchronously. Previous to flying the MUAV, students had no quantitative knowledge of the speed of an AR Drone, but rather an idea of how fast they thought it would go from watching online videos or television. Students used these previous personal experiences as a foundation for reinterpreting knowledge by constructing a quantitative assessment of AR Drone flying speed.

One of the clearest improvements was the social and emotional outcome of students with ASD. It was readily apparent that these students had an affinity for robotics, video games, and other technologies. The gamification of the experiment was particularly successful. By capturing a common interest among students of all learning backgrounds, the students with ASD appeared particularly fulfilled, presumably due to emotional fulfillment from increased social interaction. The graduate researcher had known the students for more than 6 months prior to the AR Drone experiment and saw a considerable improvement in communication between ASD students and their non-ASD peers. Singling these students out for individual assessment would have been counter productive to the goal of assimilation with their peers. The assessment was made by paying close attention to these students throughout the experiment and observing their improvement.

A chief underlying goal in the quantitative research class was to teach students to give evidence in supporting a claim. This was assessed by how the students framed their answer to the question

"*How fast does the AR Drone fly*?" in the final PowerPoint presentation. The graduate researcher and teachers observed that all groups presented data gathered from the experiment in the form of various graphs and used it to support their claim of how fast the AR Drone could fly. Moreover, they used statistical calculations such as the mean and standard deviation and linked it with experimental error. Following each presentation was a question and answer session where presenters defended their claims by revisiting slides with data and expanding upon their arguments. The culminating presentation allowed students to be assessed in all three of Ferdig's criteria.[31]

6. Conclusion

With the advent of low cost technology available to the masses, many tools such as the AR Drone MUAV allow educators to promote the STEM fields with novel hands-on learning activities. In this paper we have explored the implementation of an AR Drone into a 9th grade quantitative research class. From the initial research question of "How fast does the AR Drone fly?", four classes of 25-30 students designed an experiment and gathered numerical data to support their claim. Within quantitative research categories highlighted in Ref. 8, students conducted the MUAV experiment, made practical considerations when designing the experiment, performed numerical calculations using equations from statistics and physics, and described research findings culminating in a lab report intended to prepare students for higher education.

A PBL framework in a laboratory environment provided a setting wherein students "did something" to "learn about something." Through novel experimentation, the seemingly mundane task of collecting data was transformed into an intrinsically motivating activity where students drew names out of a hat to choose roles of piloting the MUAV, timing the flight, recording data, or observing experimental error. Gamification and other inherent learning elements were used to appeal to students with ASD, who comprised 12% of the student body. Although these students face proprioceptive and social difficulties, the gamified MUAV experiment provided them an alternative opportunity to develop collaborative and social communication skills. To increase excitement in students of all learning backgrounds, the graduate researcher implemented a situated cognition model by posing as a member of a DoD affiliated lab, telling students that their research to measure the AR Drone speed was essential in securing a highly competitive grant. Throughout the lab experiment and post analysis, the graduate student applied elements of social constructivism to bridge the scientist and the classroom by asking questions to link students' personal experience with the experimental phenomena they observed.

The graduate researcher and quantitative research class teachers anticipated and observed a tremendous level of excitement surrounding the experiment. This significantly contributed to the students' eagerness to be actively involved in conducting the experiment to the best of their ability. Following the announcement of the experiment to the first class, a contagious level of eagerness bled into other classes, whose peers shared the details of the project before it was proposed to them. Students demonstrated appropriate use of technologies by successfully flying the AR Drone with a customized video game controller, timing the flight with a stopwatch, making calculations with Microsoft Excel, designing graphs to visualize data in Microsoft Excel, and presenting evidence to support a claim using Microsoft PowerPoint. From the gamification learning element to the requirement of participation to gather and analyze data, the graduate research observed heightened social interaction and a positive emotional outcome among students with ASD. Lastly, by asking students to describe other ways they might test the AR Drone, they were required to reflect on how they learned and provide feedback regarding challenges faced. This revealed a learning outcome by showing students' abilities to use scientific terminology to describe possible ways a teacher might design a similar high school level lab in the future.

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