

Ham Radio as a Gateway for STEM Education

An Interactive Qualifying Project
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ABSTRACT

Getting students interested in careers in technical fields is an important step in the process of creating future scientists, engineers, and lifelong learners. This project focuses on understanding how young children can be motivated to study STEM.

Three activities were developed, each with the goal of effectively engaging and teaching primary and secondary school students about the intersection of amateur/hobby radio with STEM. First, a series of Minecraft lesson videos were developed to teach students about wireless communication. Second, a direction-finding demonstration was implemented to give students experience with wireless communication systems. Finally, a quiz generator to help students obtain an amateur radio license and join the global radio community was created to maintain a continued interest in STEM fields. Methods of determining the effectiveness of these activities were analyzed to suggest effective paths for using amateur radio as a STEM education tool.

Working with the students of New England Science and Technology (NEST), this project applied hands-on demonstration and educational video game content to help young learners discover the joy of scientific achievement.

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M.A., C.E., K.G.H., A.K., A.M., M.R.

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EXECUTIVE SUMMARY

Background

Out of surveyed Americans who were interested in pursuing a STEM (Science, Technology, Engineering, Math) career but chose not to, 63% responded that their reasoning for not pursuing their interest was that STEM subjects was too hard (Kennedy et al., n.d.).

In the United States, teachers at the K-12 school level have limited time to become experts in new technological areas, the way they would need to be to encourage interest in the wide array of STEM fields that students would, in a perfect world, be able to pursue equally. This leaves a clear hole in the educational process—students simply do not have enough time or resources to be exposed to many aspects of STEM which may one day influence their career.

Amateur radio is a powerful learning tool to introduce young people to STEM by providing a hands-on, experimental approach (Lennon, 2016b). It also has the innate benefit of being learnable on one's own, leaving space for students to engage with the hobby in their own time. This project focuses on developing three activities to be used by educators and the American Radio Relay League (ARRL) to both excite and facilitate an influx of young people into STEM.

Results

Three activities were developed, each with the goal of effectively engaging in and teaching primary and secondary school students about topics where amateur radio intersects with STEM. These activities were developed after initial field studies at the 2023 Eastern States Exposition in Springfield Massachusetts and the Girl Scouts “Geek is Glam” Exposition on the WPI campus.

First, a series of Minecraft Lesson Videos were developed to teach students about wireless communication using Radiocraft (*The Radiocraft Project – Immersive, Challenging Minecraft Communication*, n.d.). Radiocraft is a modification which adds amateur radio content to Minecraft, one of the most popular video games in the world. The lesson videos are short form in order to mirror current social media formats and to be sure they are easily digestible for students. These serve to engage primary and secondary school students in amateur radio.

Second, a direction-finding demonstration was implemented to give students experience with wireless communication systems. Skill acquisition which develops confidence in STEM topics is reflected in the direction-finding activity. Finally, retention in STEM fields is enabled by using a quiz generator to help students obtain an amateur radio license and join the global community of radio. Different methods of determining the effectiveness of the activities were analyzed to suggest effective paths for using amateur radio as a STEM education tool.

Final Recommendations

Three activities to promote STEM, while focusing on radio, are recommended for use in both classroom and workshop environments by both educators and the American Radio Relay League (ARRL). The activities are not tested with a student audience. Obtaining feedback from the audience to improve and create new modules would be extremely helpful. Activities can be updated to those presented by other sources, including the ARRL, or completely new. The activities should follow our rubric. Finally, success within the project should be tracked.

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CHAPTER 1: INTRODUCTION

We live in an increasingly technologically complex world. In the not-so-distant past, information was closely held in bastions of knowledge like the Library of Alexandria, the Imperial Library of Constantinople, the Wenyuan Pavilion, or the Benedictine Admont Abbey. In contrast, knowledge has become a public necessity. As a global community, we depend on these advanced technologies to provide us with knowledge on both current events and future trends. This vital information includes weather forecasts, crop yield predictions, travel route optimizations, new virus identification, wind turbine designs, to reviews on the latest video games.

Advancements in computing and communications have accelerated the complexity of technology. Using these inventions does not correlate with understanding them. Treating our technological devices as a “black box” with an unknowable interior is tantamount to believing in magical devices. This viewpoint gives in to Clarke’s Third Law, “Any sufficiently advanced technology is indistinguishable from magic.” (Clarke, 1968) The outcome of this belief is to accept the unknowable and not contribute to its advancement. Science, Technology, Engineering and Mathematics, also known as STEM, curricula attempt to address the “black box” phenomenon. Learning about the physical world and the methods that are used to build useful models allows us think critically and predict possible outcomes which opens the “black box.” Although wireless communications is not the only subject in STEM, it exemplify “black box” technology, utilizing electromagnetic waves that are invisible to the human eye. Yet, wireless technology shows incredible importance in today’s infrastructure (*Basic Knowledge of Wireless Communication*, 2023).

Thus, having a strong, STEM-educated workforce is imperative in today’s society. However, there remains some disagreement as to whether there is a shortage in the STEM workforce (Hira, 2022). Irrespective of whether there is proper evidence for either claim, a Pew Research Center Study indicated that a popular reason that young people do not pursue a degree in STEM is because they think it is too hard. In the study, 63% of Americans who were interested in pursuing a STEM career but did not, noted that STEM subjects are too hard (Kennedy et al., n.d.). With this project, we focus on addressing the belief that STEM careers appear too difficult rather than grappling with causes of a STEM workforce shortage.

In the United States, teachers at the primary and secondary school level have limited time to become experts in new technological areas (Hobbs & Porsch, 2021; Margot & Kettler, 2019). They rely on lesson plans developed by experts to develop a curriculum for their classes. A secondary consequence of the limited time that teachers have is that young students are not introduced to STEM at an early age, either in the home or at school (Slavit et al., 2016). Students do not get the chance to exercise their cognitive abilities and experience the joyous and natural curiosity that drives many to pursue STEM. When they are introduced to STEM through often unengaging and intimidating lessons in school, it is no surprise that many conclude that the STEM fields are uninteresting, or too difficult. “Currently, standards and

many widely used curriculum materials fail to reflect what is now known about children's thinking, particularly the cognitive capabilities of younger children” (Reiser et al., 2007).

Additionally, amateur radio (also known as ham radio) appears to be a powerful learning tool to introduce young people to STEM. Amateur radio is used constantly in the modern day, despite many believing it to be a relic of the past; in disaster responses in which wireless communication is not possible, amateur radio is used to coordinate emergency services and other life-saving work.

The hobby combines many STEM-based subjects such as physics, computer science, electrical engineering, and mathematics. It provides a hands-on, experimental approach to learning STEM, making it an effective tool to help young people understand complex subjects (Lennon, 2016b). The American Radio Relay League (ARRL), a national association, promotes the hobby. They develop educational materials and advertise ham radio to schools (*Amateur Radio in the Classroom*, n.d.). They also provide further resources to teachers; the ARRL developed the Education & Technology Program which provides resources and training to instruct teachers on electronics and radio, allowing them to better teach the subjects to their students (*Education & Technology Program*, n.d.).

The educational system’s limitations provide a wide-open opportunity to engage young students in the STEM fields outside of the classroom. Engagement occurs because the amateur radio disciplines are both technological and social. Our project's goal was to introduce young students to amateur radio by creating educational materials to engage them. As they progress, the student will come to realize that they are capable enough to pursue a career in STEM. These educational materials targeted primary to secondary school educational levels and needed to be up-to-date and relevant to students’ experience.

Three “activities” were created with the goal of effectively generating interest and/or teaching students more about STEM. First, a series of Minecraft Lesson Videos were developed to teach students about wireless communication using Radiocraft, a modification to the game that introduced ham radio hobby content (*The Radiocraft Project – Immersive, Challenging Minecraft Communication*, n.d.). Second, a direction-finding demonstration was implemented which displayed an important communication concept in wireless communication systems. Finally, a quiz generator was created to help prepare students for the ham radio license exams. Different methods of determining the effectiveness of the activities were analyzed, to suggest effective paths for using ham radio as a STEM education tool.

CHAPTER 2: BACKGROUND

STEM curricula have been identified as an important contributor to the workforce of the future (*Charting a Course for Success: America's Strategy for STEM Education*, n.d.; Honey et al., 2020) but we also believe that understanding technology is important for functioning in a technology-based society without treating technology as magic. The ideal time to engage students in technology is early, so that they understand that there are principles behind technology and recognize societal issues so that they can choose to behave ethically.

Importance of Science, Technology, Engineering and Math

Educational experts often champion STEM curriculum for its role in workforce development, responding to the growing need for technologically adept professionals in our dynamic world. However, the conventional approach to STEM education has frequently emphasized technical skills like computer literacy, basic science, and mathematics without sufficiently integrating broader social contexts (Nadelson & Seifert, 2017). While the ability to harness an entrepreneurial mindset, innovate, launch businesses, and identify market opportunities is a compelling aspect of STEM learning, it's essential to recognize its multifaceted nature. Beyond its undeniable economic and entrepreneurial advantages, STEM education also nurtures critical thinking skills, creativity, and ethical reasoning, equipping learners with the tools to navigate complex societal challenges (Dogan & Kahraman, 2021). By exploring the ethical and social implications of scientific and technological advancements, students develop a deeper understanding of issues such as equity, sustainability, and social justice, thereby fostering responsible citizenship (Ratcliffe & Grace, 2003). Moreover, STEM education cultivates an innovative mindset essential for driving economic growth and technical progress while simultaneously promoting broader societal well-being. In this holistic view, the importance of STEM education encompasses both economic prosperity and the cultivation of informed, ethical, and socially conscious individuals poised to make meaningful contributions to society.

Contributors to Low STEM Engagement and Ineffective Teaching

Given the increasing importance of STEM in primary and secondary education within the United States, the low engagement of young students in STEM has become a frequently discussed issue. Pre-pandemic assessment scores in areas like math decreased for the first time in many years among fourth, eighth and twelfth graders in the United States (*Science and Engineering Indicators 2018*, 2018). Unfortunately, socioeconomic factors and access to affordable higher education contribute to the problem as well (*The State of U.S. Science and Engineering 2022 | NSF - National Science Foundation*, n.d.). Also, it appears clear that many young STEM students often express discontent with learning STEM subjects, as they may fail to recognize the tangible impact that knowledge in these areas can have on societal progress,

individual well-being, national advancement, and global welfare. Furthermore, the issue of perceived difficulty of STEM highly impacts young people's interest in the subject. This creates a sense of intimidation felt by young students which would clearly negatively impact their attitudes towards the STEM subjects (Osborne et al., 2003).

Additionally, the lack of exposure to STEM from an early age deprives many students of the opportunity to develop foundational skills, understanding, and appreciation for the STEM fields. Early exposure to STEM increases interest in STEM careers (Gustafson, 2022). Moreover, the perception that STEM has limited relevance to students' lives and interests may further diminish their motivation and engagement in these subjects (*A Framework for K-12 Science Education*, 2012). This is one of the most important factors in our view and is a core motivation for our focus on the popular video game, Minecraft. Compounding these challenges is the inadequate provision of career awareness and guidance, leaving students uninformed about the diverse array of opportunities available in STEM-related fields (Archer et al., 2010). Finally, the perception of STEM disciplines as lacking in creativity and innovation may deter students from exploring these areas further, reinforcing misconceptions and stifling their enthusiasm for STEM learning (Council, 2013).

STEM is typically taught as a series of building blocks with the goal of testable facts (Fensham et al., 1994) with the scientific method as just another testable fact. A cursory analysis of many textbooks from the elementary and high school level from major textbook publishers indicate that there is an emphasis on "definitions" and "skills" that emphasize unitary pieces of knowledge; whereas the scientific method is described, in summary references like Encyclopaedia Britannica (Britannica, 2024), as a process. This need of understanding the process of inquiry is also highlighted in other English-speaking countries. (Newton, 2022) Lesson plans written by those experienced in STEM can be written by experts with explicit open inquiry in the subject areas they represent.

Writers of lesson plans should allow for a conceptual model and inquiry into that model which can test its predictive power. Factual knowledge does have a role in lesson plans and learning. Facts provide the foundation for hypothesis generation. The lesson plans developed here emphasize the process of utilizing hypothesized models and tests. In the special case of FCC certification, the test databank is large enough for each level to make it challenging to use recall to answer the questions and their variants. Mental models are necessary to pass the exam without excessive retries. A test databank with conceptual context and recommendations for study materials for the missed questions helps train mental models that result in correct answers.

Curriculum Aids for Open-ended Inquiry

Teachers' time is limited, not only do they work during the regular school year while classes are in session, but they also work on administrative tasks, professional development, and curricula for the coming year. Curriculum aids for primary and secondary school teachers can help reduce the burden. Curriculum aids come in many forms. One of the primary ways in

which teachers begin is a purchased curriculum from textbook publishers. These can be purchased by school districts to cover core classes (Loveless, Tom, 2014; Tomassini, 2012). There are a large number of databases of open-source curricula (Rayl, 2017) of which the ARRL provides a unique set of lesson plans related to communications technology.

The structure of lesson plans remains a debated topic. Rigid lesson plans, according to Panasuk and Todd, stifle open inquiry (Panasuk & Todd, 2005). In contrast, Rusznyak and Watson argue for a predictable format. Open-ended questions promote inquiry and further exploration. The challenge for the predictable format is that open-ended questions often require a base level of knowledge to pursue inquiry. Having many questions is unwieldy. Our goal is to present lesson plans that have a few open-ended questions that probe different levels of knowledge at the end of an experiential project to span different education levels.

Wireless Communication Technologies

The radio frequency spectrum resides roughly between kHz to THz, the wavelengths range from 3000 meters to millimeters. The varying frequencies interact differently with building structures, terrain, and atmospheric conditions. Short wavelengths can carry lots of data but have minimal penetration depth in buildings and across rough terrain. Communications at this wavelength is primarily line-of-sight. Wi-Fi 6, 6 GHz, is typical of this type of interaction as it is only capable of transmitting data at high speed through just a few gypsum walls. Lower frequency signals, like those of cell phones, can travel through many walls or 8 km. Much longer wavelengths, like 100 meters, can travel even further through the atmosphere by reflection from an ionized layer of the atmosphere, the ionosphere. The ability to transmit is also limited by interference from natural and artificial sources. The interference can corrupt the information in the signal. The usefulness of wireless communication is the ability to transmit information from point to point. (*Basic Knowledge of Wireless Communication*, 2023)

The usefulness of wireless communication is undeniable. Cellular phones are ubiquitous both in the developed and the developing world. Within the developed world, vehicles from automobiles to Zamboni machines are capable of wireless communication, balloons and satellites provide connectivity with ground stations, even the movement of weather and wild animals are being tracked with wireless transmitters.

The sociological aspects of radio communication are deep and not fully recognized. Activities within the ARRL community are broad. Older generations recognize shortwave AM radio broadcasts from government and government entities, like Voice of America and Deutsche Welle. Many small countries maintain shortwave broadcasts to reach remote areas within their countries and expatriates. Nonprofit broadcasters use the shortwave spectrum to reach far-flung audiences. Amateurs regularly communicate using Morse, digital and voice on shortwave. Perhaps more importantly, many communications about safety, from police, fire, military, and federal disaster response are transmitted wirelessly using both simple and complex protocols. These are ethical uses.

Unethical uses of wireless communication are also possible. Snooping, hacking, and blocking using Flipper Zero, GPS spoofers, and Wi-Fi jammers are becoming social issues in the United States with security gurus warning of Bluetooth hacks and discussion boards hosting posts suspecting that delivery drivers are jamming homeowner wireless security systems. Understanding the societal effects of usage, snooping and denial of wireless technologies is an important part making informed decisions about the technology.

Amateur Radio

Ham radio, officially known as amateur radio, is the use of radios for recreation and service. People across the world and space engage in this hobby, communicating with each other and experimenting with wireless communication technology. Ham radio can serve as an introduction to STEM, requiring knowledge of basic radio technology and principles to participate (*What Is Ham Radio*, n.d.). It combines subjects such as physics, computer science, electrical engineering, and mathematics all in one hobby, in a hands-on, effective learning tool (Lennon, 2016b). However, a ham radio hobbyist may not need expertise in all these areas, they only need be proficient with the basics in order to operate a station.

To use an amateur radio station legally, operators require licenses. The ARRL separates the license into three classes: technician, general, and extra. Each license level requires additional knowledge and expertise to obtain, starting with the technician class license serving as an entry-level choice to begin operating a radio legally. The technician class license requires an exam of 35 multiple choice questions on radio theory. With enough studying, younger operators can pass the exam and receive their license (*Getting Licensed*, n.d.). However, requiring a license serves as a potential barrier to entry for those looking to become acquainted with the hobby. For the hobby to attract as much interest as possible, the process of acquiring a license should be as accessible and smooth as possible, to avoid deterring potential hobbyists while ensuring the necessary fundamentals and information for the hobby are learned. Many have taken steps to remedy this problem. The ARRL has developed a simple and accessible study tool for each license exams (*ARRL Exam Review for Ham Radio™*, n.d.). Companies such as Ham Radio Prep develop video in depth video lessons and extensive study materials, albeit an expensive option (*Ham Radio Prep – Ham Radio Online License Class*, n.d.). Finally, the ARRL has made the cost of the exam itself more accessible to youth, offering a grant that covers the one-time \$35 application fee for new licenses and reduced exam fees for candidates under 18 years old (*Youth Licensing Grant Program*, n.d.).

In combination with the license exam acting as a barrier to those interested in becoming a ham radio operator, the hobby struggles to recruit young members. Despite being so beneficial to developing STEM skills in youth, the demographic of those interested in ham radio consists mostly of white men in their 60s and 70s. As the population of amateur radio enthusiasts grows older, many question if too few young people remain to sustain the hobby. In recent years, the growth in the number of U.S. amateur radio licenses has stayed at 1 percent, with around 7,000 new licenses per year. The once novelty of talking with people across the world has become easy with the ubiquitous technology of cellphones. Additionally, young

people now grow up more familiar with text contact instead of phone calls, making person-to-person amateur radio contacts more unfamiliar (Pepitone, 2020).

Yet, the American Radio Relay League has taken efforts to include more young people in the hobby. It sponsors activities dedicated to amateur radio youth, such as Kids Day, which works with school clubs and provides resources for ham radio classroom activities. Companies and individuals who have an interest in amateur radio have taken steps to make the hobby more accessible and integrated with today's technology. Some companies have made amateur radio more accessible to youth by selling cheaper software-defined radios, increasing their accessibility. Interfacing with radios using software intrigues youth, taking advantage of the growing field of computer programming (Pepitone, 2020). Others have made radio stations connected to the internet. Users may control radios remotely using their phones or personal computers (Nurse, n.d.).

Although effective for some, many amateur radio enthusiasts disagree about how to interest the youth in the hobby. With operators having such a variety interest such as robotics, casual chatting, contesting, emergency communications, or foxhunting just to name a few, it appears difficult to interest youth in amateur radio through a single avenue. However, this leaves ample opportunity to try different creative approaches to interest more youth in the hobby, thereby increasing their interest in STEM.

Amateur Radio for STEM Education

Educators can already make use of amateur radio in STEM education. The ARRL has published curriculum educational materials for classroom use. The hands-on experimentation and learning required by amateur radio makes it a unique and effective tool to demonstrate complicated STEM subjects (*Amateur Radio in the Classroom*, n.d.). Learning about the analog components of a radio helps students learn about electrical engineering. Investigating the propagation of electromagnetic waves teaches children physics concepts. Young people can practice their programming and computer science skills by experimenting with software-defined radios. Through the technical nature of amateur radio hobby, students intuitively learn STEM subjects and skills. Middle and High Schools have created programs and projects to teach about STEM. These programs perform a range of activities, from the basic teaching about electronics to the tracking and launching weather balloons (Lennon, 2016a).

Diggins conducted a study asking similar questions to this project (Diggins et al., 2023). The study investigated whether participating in the International Space Station School Program affected students' interests towards STEM subjects and careers. The program tasks students with establishing contact to the astronauts on the International Space Station through amateur radio. After establishing contacts, the students perform a question-and-answer session with the astronauts. Through collecting data using a mixed methods research model with pre- and post-event online questionnaire from 236 students and 31 teachers, the study used a t-test to investigate their results. They found that science was the only subject that showed a statistically significant increase in interest from pre- to post- survey, albeit all the subject areas

showed growth in the sample. Although the study primarily attributed the change in attitude towards STEM to the interaction with the inspirational role models of the astronauts, amateur radio played an important role facilitating communication.

Background Specific to the Activities

Activity 1: Minecraft Videos

Minecraft is one of the most popular video games of all time with over 300 million units sold since being launched on computer, tablet/mobile, and console platforms. The game features 3D sandbox gameplay, with players building and doing whatever they want within the game's constraints with no required goals. Many people modify the game to add extra features. Radiocraft is one such modification that enables simulation of ham radios into the computer version of the game. It provides educational and accurate representations of the amateur radio hobby to the popular game. The mod's development has seen support from the ARRL, providing a \$22,000 grant, as the organization sees the project as a promising initiative for people interested in STEM.

Activity 2: Direction Finding

“Fox hunting,” also known as transmitter hunting, is a popular ham radio activity based around radio direction finding. Participants use a radio receiver and wireless communication principles to find a hidden transmitter. Mainly, the competitors use knowledge of antennas, which may receive the transmitted signal differently based on operating conditions such as distance, desired frequency, and received signal strength to locate the transmitter (Suparman & Homam, 2019). However, they may use other less common amateur radio principles to achieve the goal such as phased array techniques.

A phased array is an important concept in wireless communications concept where a computer controls an array of antennas to better transmit or receive a signal. By fixing the antennas in an array, the operators delay signals, transmitted, or received, from each antenna to construct a clearer signal. Phased array receiver beamforming involves the delay of signals in time according to a phase relationship at the receiver to constructively enhance the signal received. Depending on the angle transmitter signal reaching the receiver antennas, the source hits one antenna in the array before the others and so on. Using this technique, the direction of the radio frequency, RF, source can be determined by introducing phase delay to one of the signals until the peak constructive signal strength is reached (Mailloux, 2017). Figure 1 demonstrates the concept visually, where an RF signal reaches antenna elements at different times. By using the time at which the signal reaches each antenna element and knowing the distance between antennas, the direction of the RF source, the transmitter, can be calculated. As opposed to antennas that move mechanically and determine the direction of an RF source based on received signal strength, phased array implementations operate much faster and

more efficiently, making this technique popular in new communication systems (Jon Kraft, 2020).

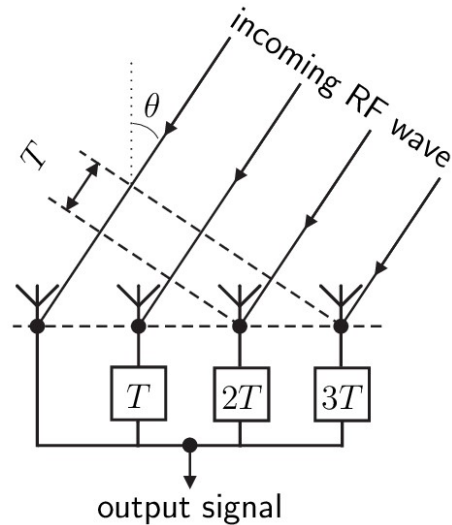


Figure 1. Phased Array Receiver Beamformer (Tijmes et al., n.d.).

There is a way to implement the phased system inexpensively. One implementation uses a software-defined radio, also known as an SDR, which creates basic radio components using computers instead of analog radio hardware. Using an SDR, one may program software to create a simple phased array receiver beamformer that determines the angle of an RF source (Jon Kraft, 2022).

The concept of phased array beamforming has many applications in the real world of wireless communications. 5G communications systems use beamforming to focus cellphone signals on users instead of radiating signals in all directions, as was done by communication systems of the past. Radar uses beamforming to track and follow a target in a narrow area instead of mechanically manipulating one large antenna to scan a range. Additionally, communication systems for low-earth orbit satellites use phased array beamforming to precisely and quickly target receivers (Jon Kraft, 2020). The principle of time of arrival used by phased array beamforming even be useful in understanding a technology responsible for self-driving cars, lidar. Light detection and ranging (lidar) uses pulses of electromagnetic waves received at sensors to map a 3D environment. Both technologies rely on knowing the precise time a signal from a transmitter reaches a receiver for the purposes of direction finding or computer vision (Wandinger, 2005).

Activity 3: Quiz Generator

In addition to engaging students in STEM-related activities, especially those around the practice and usage of wireless communications, we aim to prepare the students to take and pass the Ham Radio License examinations from the Federal Communications Commission (FCC). The quiz generator introduces the students to all the topics on the exam in a way that should be both educational and brief enough to remain fun.

CHAPTER 3: METHODS

The purpose of this Interactive Qualifying Project was to develop amateur radio and wireless communication activities and analyze how they affect young people's attitudes toward STEM. A common misconception regarding STEM among young people is that it is too challenging to get into. By creating these materials, we hoped to show that STEM subjects are not uninteresting or too difficult by creating engaging, understandable materials to convey complex amateur radio subjects in an understandable way.

We took three approaches to developing activities for STEM curriculum, referred to here as Activity 1, Activity 2, and Activity 3. We decided upon a few different approaches. Firstly, we wanted to try an approach of teaching younger audiences through computers. As many young people are exposed to screens, whether through computers, game consoles, or TV, they can learn a large amount of information through screens. Such logic was applied to Activity 1 and 3. Secondly, we wanted to test the approach of using physical applications in the real world. Such concept comes into play when discussing how children learn. We theorized that children could learn from tactile feedback when trying something new. This logic was applied to Activity 2.

Activity 1 explores a video game simulation of amateur radio equipment and low frequency radio communications and its use to engage students in radio communications through the fun and familiar context of video games. Such simulation is a modification of Minecraft. Within the Minecraft video game, users can create modifications that implement concepts that were not intended by the original developers. Therefore, a modification was created by Lucas Elliot called Radiocraft. Radiocraft implements amateur radio and other forms of telecommunication. The simulation environments with Minecraft and Radiocraft let students experiment with ham radio in the virtual world. Simulation environments allow students to practice without the fear of breaking physical hardware or inadvertently violating social rules. Through the students' experimentation, we can attempt to understand the variables with which young people become interested in STEM and new hobbies in general. Due to the high interest in Minecraft applications, we decided to extend the experiment of Activity 1. Therefore, to get more potential players interested in trying out the Radiocraft modification of Minecraft, we chose to develop four videos as a method of engaging and exciting students. Such videos are short form—no longer than five minutes each. The purpose of shorter form content was so children could be honed into a subject. We predicted that. Due to the change in shorter social media content being consumed at higher rates within the past five years or so, we believed that multiple shorter videos would work better for younger children. The videos were devised into such categories:

Video 1: A broad overview of the modification and what it lets you do in-game. The idea of this video is to show the amazing capabilities that radios/wireless technology enable within the virtual Minecraft world, a context that is likely to be familiar to the viewer. It serves as an introduction to the topic.

Video 2: A quick set-up guide for building a simple working radio using the Radiocraft modification. This guide is step-by-step and slower paced, so that the previously shown-off capabilities seem accessible and easy to implement within the Minecraft world.

Video 3: An explanation of the user interface for one of the in-game radio's and how to use it to communicate with friends on the same server. This allows viewers to see (and try for themselves if they download the Minecraft mod) a simplified version of how radios are operated in real life. The goal of this is to give the viewer/player a feeling/idea for how to operate a tool that seemed overly complicated or too hard not so long ago.

Video 4: Briefly and simply explains fundamental concepts like frequency, voltage, resistance, and current. This finally makes the direct connection from what the viewer has seen being done in a video game that potentially feels remarkably familiar and fun to them to real and powerful STEM concepts.

Activity 2 gives students the opportunity to use wireless radio gear to demonstrate direction finding. The build touches on the important wireless communications concept of phased array beamforming. It involves a more physical, tactile approach. Due to this physical approach, the students get to move around physical objects, which can certainly help engage in learning. Such could also lead to other sub-interests in ham radio such as foxhunting and gain interest in community-wide days that utilize ham radio such as World Amateur Radio Day.

Activity 3 utilizes a quiz generator based on the FCC licensing examination questions. The quiz generator reinforces classroom learning and provides a path to practical skills. A major roadblock in the path to becoming savvy at ham radio has historically been receiving a license. Due to this roadblock, many younger students may feel that getting into ham radio is too hard or not worth the time. Also, many young people simply do not like to be required to take a test to get further into a hobby. Utilizing the quiz generator provides an online resource that makes the process easy to try.

We first attended in person events relating to amateur radio and STEM education to see how people interact with hands-on activities like a morse-code beeper activity we set up for the event and virtual activities like playing Minecraft on a laptop we brought. This helped us get a better sense for how our intended demographic interacts with ham radio activities. We used the experience gained at the events to help inform the design of our three activities. We intended to test our activities using mixed method research design with a pre- and post- survey to measure how the children's interests in STEM changed by participating in the activities.

Problem Assessment

To understand how to engage elementary, middle, and high school students, we participated in three events. We staffed an ARRL booth at The Eastern States Exposition in Springfield, Massachusetts on September 24, 2023, a "Geek is Glam" Girl Scout STEM exposition booth on the WPI campus on October 14, 2023, visited New England Sci-Tech (NEST)

in Natick, and staffed a booth at the Winter Field Day event at NEST on January 7, 2024. These three events provided useful information we used in developing the three activities.

The Big E Booth

At the Eastern States Exposition, also known as the Big E, we spent a day at the ARRL booth and touring the Exposition to find inspiration for our projects. We arrived with two goals for the event, to understand what the ARRL booth represented to both the ARRL members and to the public, and to understand what other exhibitors were doing to attract our target audience. There were three types of visitors to the ARRL booth:

- adults who remembered radio communications from their youth.
- curious elementary school students.
- college-aged students interested in the hobby.

At the booth, fair attendees interacted with premade morse code kits, shown in the top left of Figure 2. Using the morse code keyer, we encouraged participants to spell out their names using the morse code alphabet. Additionally, many pamphlets and informational materials laid on top of the table, allowing attendees to easily walk away with supplemental information on “getting started” with the hobby. Finally, the bottom of Figure 2 shows a software defined radio project, consisting of a weather balloon radio transmitter and receiver.



Figure 2. Materials on Big E Fair Table (Temples, 2023).

We noticed the most popular resource on the table was the morse code alphabet. Many participants found the novelty of pressing the button on the morse code keyer and hearing the buzzer sound most interesting. Young visitors had the most fun attempting to spell their names using the keyer. They were at an age at which they encountered difficulty normally spelling

their names, so spelling their names in morse code also served as practice for spelling their names in English. This inspired our Morse code activity for the Geek is Glam event.

Only the elementary school students were members of our target audience for this event. They asked casual questions like “What can you do with radio?” and, “What is this about?” The college-age students had an engineering background and were already aware of the technology. The mostly older white male adults seemed already familiar with the hobby.

Other booths attracted larger crowds. Interactive activities that encouraged individuals to approach and had social reinforcement seemed to be the busiest. The LEGO exhibit had the largest amount of traffic and conversation. The initial attraction seemed to be having LEGO blocks available for creative play, the consequence was that visitors had conversations with the exhibitors and other visitors.

There is a clear difference between activities that might create initial engagement and activities that create retention for amateur radio. Designing for engagement and retention is not well represented in the literature, despite many clubs having an aging population and needing new members. Unlike Social media (Howard, 2009) and sports organizations (Mandić et al., 2023) amateur radio clubs do not design for engagement or retention. A bridge between technological interests and long-term social relationships seems to be the most effective path. Of our projects, the Minecraft short form videos and the fox hunt are good examples of technology used as engagement. The quiz generator provides a path towards social engagement since licensure is the path to communicating with other amateur radio enthusiasts.

"Geek is Glam" Booth

The next event we attended was the Girl Scouts “Geek is Glam” Exposition. The event served as an opportunity for 327 girl scouts in middle school to explore technology on the WPI campus. Our team had a booth for which we had prepared three activities, a demonstration of the Radiocraft Minecraft mod, a Morse code interpreter, and a board game, “Robust Radio Networks.” The Radiocraft mod was running on a laptop where the scouts could interact with it. The Radiocraft demonstration immediately attracted scouts. Both the subject matter and the on-screen activity were both important to engagement. The Morse code interpreter was also running on a laptop with a Morse key attached. Scouts were encouraged to try spelling out their name in Morse code on the key. Success meant that the laptop displayed their name. Scouts were intrigued by the challenge as an alternative to the Radiocraft demonstration. A few scouts were interested in the board game. The game is visually obscure. It more closely resembles mathematics board games, like Piet Hein and John Nash’s “Hex,” where the objective needs explanation and is not self-explanatory like “Monopoly” or “Chutes and Ladders.” This age group appeared externally driven by social pressures, including the school environment.

New-England Sci-Tech (NEST) Visit

For our next group event, we visited New England Sci-Tech, also known as NEST, in Natick Massachusetts. We visited this non-profit STEM education center and maker space for youth on a normal weekend morning where around ten children worked on various projects (*About Us*, n.d.). We interacted with the attendees to gauge their interest about amateur radio and STEM. On this trip, we learned about the popularity of Minecraft at the center. Upon arriving at the center, the children were already playing Minecraft, without any outside influence. Additionally, we learned about the relationship the center had with amateur radio. NEST administered amateur radio license exams. In fact, many of the people that we talked with, including the children, were licensed ham radio operators. This visit showed us that an activity involving the Radiocraft mode would have likely interested children at the center, as it combines Minecraft and amateur radio, two hobbies popular at the center.

Winter Field Day Booth (at NEST)

For our final event, we staffed a booth with demonstrations of both our direction-finding activity and the Minecraft mod along with our Minecraft videos. The event served as an opportunity to see how people interacted with our activities. Winter Field Day is a way for licensed amateur radio operators to exercise their wireless communication skills both at home and out in the field. It is a points-based competition where each participant attempts to make as many contacts with others as possible with bonus points being awarded for accomplishing challenging tasks like using a non-commercial power source, contacting satellites, and more. Additionally, there were exciting and fun activities including planetarium shows, a ham radio movie marathon, and a potluck. Going to this event gave us a deeper understanding of what makes ham radio and wireless communications fun for both adults and kids who enjoy it as a hobby. It also allowed us to see how our two activities are compared to the applications of ham radio that are both practical and fun. This was important to us because this is what we wanted to communicate through our activities. We wanted to communicate that working in STEM can be both extremely practical and extremely fun, which this event was clearly a prime example of. Seeing this clear example gave us an understanding of how to communicate our message to a larger audience.

Solution Justification

While the above felt like great indicators that our activities had the chance to be successful/impactful, before embarking on our mission to tackle the problem of low STEM engagement, we made sure to thoroughly research how to best reach young students and what has been shown to be effective in the past. Based on this research and our personal experiences at the events mentioned in the previous paragraphs, we believe our methods have great promise to help us achieve our goals.

Minecraft Activity

It has been shown that video games and computer simulations are enticing to students as learning tools. According to “The use of computer and video games for learning” by Alice Mitchell and Carol Savill-Smith, when given the choice between using a computer simulation and reading an article for an independent study, more than 69% of freshmen engineering students chose the computer simulation (Mitchell & Savill-Smith, 2004). Importantly, it has also been shown that not only are these tools enticing to students, but they are also effective at conveying the lessons and knowledge they aim to impart. The study mentioned above assessed the students’ learning with an examination and the result was that the experimental group (the group that learned the content using the computer simulation) tended to learn more. It goes on to say that things like instant feedback and visual and causal images allowed students to see what happens when they applied their knowledge.

Minecraft appeals to youth and promotes social activities. According to a 2017 study which surveyed 753 children ages 3 to 13 years old, 40.5% of children surveyed responded that they have played Minecraft. Older children ages 9 to 12 were statistically significantly more likely to play Minecraft than younger children ages 3 to 5, 68% to 11% of the populations surveyed. Of those who played Minecraft, 65% played on tablets or mobile devices and 22% played on computers. However, of children in the oldest age group (9 to 12) who played the game, 37% played on computers. Finally, 80% of children surveyed who played the game have at times played with other people and around 45% playing with other people most often (Mavoa et al., 2018). The results of this study support the potential effectiveness of using Minecraft as an introduction to STEM and ham radio, as many children play the game on a platform capable of the Radiocraft mod and can use the mod with friends.

Additionally, educators already use Minecraft for learning and STEM education without modifications to the game. Organizations offer Minecraft camps intended to create a friendly learning environment for children. For example, secondary schools in Northern Ireland use the game as an educational tool (Ito, 2015). Furthermore, a 2017 analysis indicates that Minecraft helps develop proficiency in planning and visual-space skills, which has a strong correlation to success in STEM fields (Hughes, 2017). Studies indicate that interest in gaming outside of an educational environment leads to development of technical and social skills, indicators of future information technology and STEM careers (Hayes, 2008). Even without the addition of a radio mod, Minecraft serves as a strong learning tool for STEM education as children develop important technical and social skills.

Direction Finding Activity

In approaching the challenge of using ham Radio and its related concepts to increase the interest in STEM related fields, it presents us an opportunity to use either theoretical or practical education to overcome the challenge. While theoretical learning can cover a wide variety of materials, it often has its limitations. We decided to take the practical approach as it allows us to turn our activity into something engaging and fun. A study conducted on the

impact of practical experience on theoretical knowledge at different cognitive levels shows a significant increase in the ability to apply the knowledge learned in a real-world setting (Leask et al., n.d.). This study had a cohort of students with very limited clinical experience along with a group of veterinarians. At the end of the study, it was concluded that there was a significantly positive impact on theoretical knowledge.

With the help of our direction-finding activity, we can immerse students in the practical elements of ham Radio communication. Here, they not only learn the technical aspect in ham Radios but also develop the ability to critically think and learn new ways to approach real world problems in STEM fields.

Quiz Generator

Quizzes have been shown to help improve retention of material and solidify learned concepts. (Butler, 2010; Carpenter, 2012) Repeated testing in a low-stress environment allows both the teacher and the students to measure the effectiveness of classroom learning. (McDaniel et al., 2011; Roediger, 2014)(Hurst et al., 2013). Although activities such as the RadioCraft Minecraft mod and direction-finding demonstration may interest participants in STEM, means of retaining are imperative for continued STEM interest. The purpose of the quiz generator was to assist in the retention of STEM and ham radio concepts rather than introducing new ones. Youth who find themselves interested in ham radio through Minecraft and direction-finding activities may use the quiz generator to advance their interests easily and accessibly in the subjects.

Quiz generators are popular and effective resources for ARRL exam preparation. The ARRL has their own exam review program for free on its website. The program randomly presents the user with real ARRL license exam questions and their multiple-choice answers. Users can select which license exam they want to study for and even which subsection of questions they wish to study. The resource is an accessible and easy tool to prepare for ARRL license exams (*ARRL Exam Review for Ham Radio™*, n.d.). Other organizations offer quiz generators for ARRL license exam studying. For example, the company “Ham Radio Prep” offers a paid course with video lessons and access to their own quiz generator tool (*Ham Radio Prep – Ham Radio Online License Class*, n.d.). These quiz generators are sometimes slow to update with new information and lack tools for effective studying when linked with the classroom environment, so the team elected to make our own with an easily modifiable database to ensure the database was always current.

Solution Development

Activity 1: Minecraft Lesson Videos

Our first approach is to meet primary and secondary students where they are already at. Many younger students find enjoyment in watching videos and playing video games already, so

why not build engaging STEM material with this in mind? One of the most popular video games ever made is a game called Minecraft. This game, by design, allows for an extreme amount of creativity. To take this even further and really drive home the idea that the creativity that can be expressed in Minecraft can also be expressed in real life through the STEM fields, we decided to partner with a team creating a ham Radio modification for Minecraft called “Radiocraft.” (*The Radiocraft Project – Immersive, Challenging Minecraft Communication*, n.d.) From here, we were able to create entertaining and educational videos that introduce the main ideas behind the modification of the game and some simple but foundational concepts used throughout the STEM fields.

Another aspect we wanted to keep in mind for the virtual aspect of the project was to keep our videos short and attention-grabbing. With the rise of popularity in short-form video content, it has become imperative that video content is kept quick and to-the-point if it is to keep a casual viewer’s attention for any meaningful amount of time, even in an educational context (Kravchenko & Cass, 2018). However, we couldn’t fit all of what we wanted to communicate in such a short amount of time, so we settled on making multiple short-form videos that young students or casual viewers can view in rapid succession, each one capturing their attention and leading them to watch the next. This led us to brainstorm the main content to be contained within each video and start scripting each one with the previously mentioned findings in mind. A more detailed explanation of the four video topics can be found in the Findings chapter. After many iterations of scripts and edits to the final videos, we arrived at our final videos as they are today. You can find the links to the videos in the Findings chapter as well.

Activity 2: Direction Finding Activity

Our direction-finding activity sought to interest students in using the power of radio signal propagation and processing. We found the activity concept desirable as it incorporated interactive elements, allowing the students to identify the location of a transmitter antenna and see the angle reflected on the computer. The materials will be provided as a kit along with the activity description as discussed below in section, Activity 2: Direction Finding Activity.

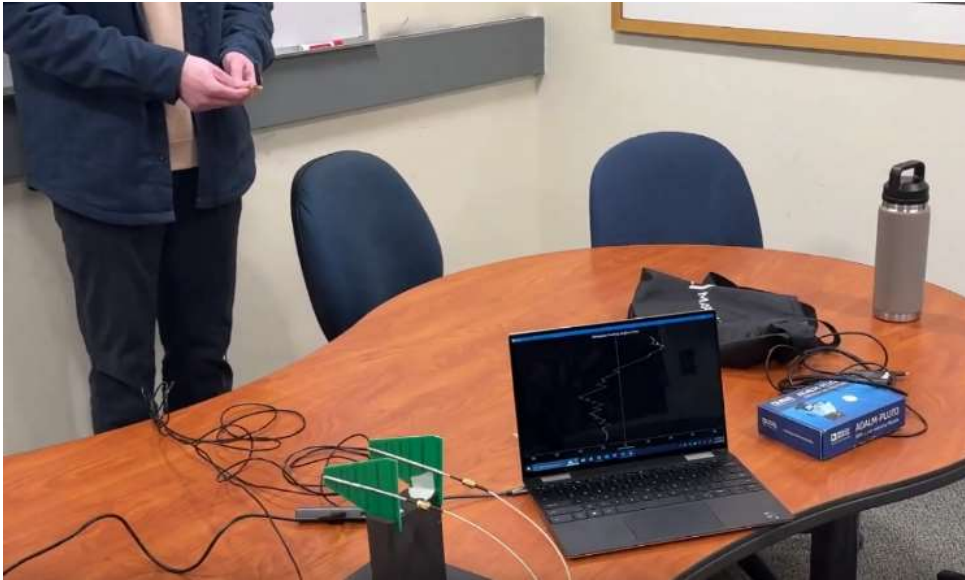


Figure 3. Tabletop demonstration of phased array antenna.

Activity 3: Quiz Generator

Flashcards are “out,” and quiz generators are “in.” There is a trend among students to take study quizzes on mobile devices. The number of quizzes based on primary and secondary school textbooks is growing fast. (Gurung et al., 2020; Mascarenhas, 2020) The popular quiz generators, Chegg and Quizlet do not offer information that allows students to consult reference material within their question-and-answer formats to improve their understanding. To this end, we created a quiz generator coded in Python 3.12 code and Pandas. The code is shown in

APPENDIX A: Python Codes for ARRLQuiz.py. The code and database are packaged into a Windows 10/11 app using autopy-to-exe which is a graphical front end to pyinstaller. (Vollebregt, n.d.) The interested reader can use the provided resources in order to package the python code and run resulting executable. The icon shown in Figure 4 is assigned to the app during the creation process to uniquely identify the app.

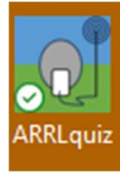


Figure 4. Icon for the Quiz App.

Once run, the app digests a comma-separated-values (csv) file containing categories and study hints along with questions, answers, and the correct answer. The database is filtered by the selected category, license classification. A specified number of randomly selected questions and possible answers is displayed. Responses are given by the student for those questions. A report is generated with the selected answers, correct answers, and recommended study resources. A detailed run through of a brief quiz is shown as part of Chapter 4, Activity 3.

The questions have been placed into 10 categories. A question may belong to many categories at once. For example, Fun-to-try is a category that frequently shares questions with Atmospheric Science and Physics. In contrast, Robotic Engineering has very few questions associated with the topic, since most of the questions posed by the FCC certification rarely refer to communication with autonomous devices. The selection criteria for questions are shown in Table 1.

Table 1. Categories for Quiz App Questions.

Category	Description
Communications	Methods of communication and terminology used in Ham-to-Ham communication.
Electrical Engineering	Antenna, electromagnetic wave propagation, circuits, and operation of circuits and how to improve operation of communications equipment.
Atmospheric Science	How the atmosphere affects radio frequency propagation, with an emphasis on weather phenomena.
Space Science	Anything outside the atmosphere, including the moon, comets, meteors, solar flares and communications with satellites.
Robotic Engineering	Remote control of programmable machines.
Physics	Fundamental phenomena, the “why.”
Mathematics	Calculations, formulae, and fundamental understanding of mathematical models.
Computer Science	Understanding algorithms.
Fun-to-try	Classroom-demonstratable projects.

There are three license levels, General, Technician and Extra. Each pool of questions requires an increasing level of knowledge. It is possible, and even likely, that a secondary school student can learn enough for an Extra license. One goal of this activity was not to preclude advanced learning. An option is given for choosing any license level.

At the end of the quiz, each question has a “response.” The response is a freeform text field in the database. Its current meaning is to provide a study guide which helps the student to understand the correct answer. The field may contain references or instructional advice. Students should be able to find the reference works and read the relevant sections. This field is currently uniformly populated with the phrase “ARRL Handbook”. Providing individualized responses for each of the 1400+ questions was beyond the scope of the IQP project. A team preparing for multiple levels of amateur radio certification would be ideal for this final documentation effort. Table 2 is representative of the table contents in Excel format.

The application is intended to have a living database. Each question pool for each of the license levels is valid for 4 years. The three question pools for the General, Technician and Extra license classes are roughly annually staggered. (*Amateur Question Pools*, n.d.) A python code, `ARRLTestPoolparser.py`, is used to roughly translate text files of the questions into csv files. The csv files are hand-edited in Excel to assure alignment between questions and answers. Misalignment can occur because the markers we use for determining breaks between questions and answers can also appear within them. The cleaned files for each license class are then concatenated into a single Excel file. The Excel file has columns added to categorize and respond to questions. This is exported to a csv file which resides inside the application.

Because the quiz generator uses an internal database representation of the csv file, questions can appear in any order within the file. Also, the file can include only questions for a particular license. Queries are used to retrieve questions that match the criteria that the student enters. Those query responses are formatted for display and then used to generate the report that each student gets. These properties allow for rapid updating of the database each year or restricting the database to a single license so that updating is a quadrennial activity.

Table 2. Top rows in the Quiz Generator database.

						Question Identifier	Question	Answer	Choice A	Choice B	Choice C	Choice D	Response
Communications	Electrical Engineering	Atmospheric Science	Space Science	Robotic Engineering	Physics								
					Mathematics								
					Computer Science								
					Public Service								
					Fun-to-try								
					License Class	E	E0A02	B	Ensure signals from your station are less than the controlled Maximum Permitted Exposure (MPE) limits	Ensure signals from your station are less than the uncontrolled Maximum Permitted Exposure (MPE) limits	Ensure signals from your station are less than the controlled Maximum Permitted Emission (MPE) limits	Ensure signals from your station are less than the uncontrolled Maximum Permitted Emission (MPE) limits	ARRL Handbook
						E	E0A03	C	300 kHz to 3 MHz	3 to 30 MHz	30 to 300 MHz	300 to 3000 MHz	ARRL Handbook
						E	E0A04	C	Only the most powerful transmitter	Only commercial transmitters	Each transmitter that produces 5 percent or more of its MPE limit in areas where the total MPE limit is exceeded	Each transmitter operating with a duty cycle greater than 50 percent	ARRL Handbook

Attempted Methods Analysis

To evaluate the effectiveness of each method, we created surveys. We utilized a survey developed in (Tyler-Wood et al., 2010) called the “STEM Semantics Survey”. This survey was created to assess the perceptions of science, technology, engineering, and math subjects by asking students a series a series of questions about their feelings on the subjects. The participants answered on a 1-7 scale with multiple feelings per subject. For instance, they were asked “To me, SCIENCE is: 1. Fascinating to 7. Mundane”. This survey instrument was chosen because it was found and tested to be consistently reliable and contained good content (Tyler-Wood et al., 2010). Also, it was chosen as it proves quantitative data, able to be analyzed using statistical methods.

To analyze the effectiveness of our developed activities, the survey instrument must be capable of measuring change in the participants’ interest in STEM. So, in our testing methodology, we planned to administer the “STEM Semantics Survey” twice, once as a pre-survey and once as a post-survey. We planned to collect responses to the voluntary survey in a google form. Additionally, we planned on collecting qualitative data by observing and interacting with the participants while they perform the activities. Observing their interest in the STEM subjects that the activities communicated or their interest in the activities would have given indications on the effectiveness of the activities.

It is important to note that this method was attempted and not successful, due to limitations with our sample population which will be discussed in the Findings Section. However, if we were to have performed an in-depth analysis of our activities, this was the method we would have used.

CHAPTER 4: FINDINGS

Results

Through this project, we were able to produce both physical and virtual interactive demonstrations, which included a direction-finding activity and a set of engaging and educational Minecraft videos. The videos introduced young learners to the Ham radio Minecraft modification, how to use it, and how it relates to some fundamental concepts in STEM. We also developed two lesson plans, one for the direction-finding activity and one involving a quiz generator.

Activity 1: Minecraft Videos

Through our work with the ham radio Minecraft mod team, we were able to use their modification of the game to create videos that demonstrate things like the major components used in radios, how to use radios, and some fundamental concepts in all STEM fields, but particularly within the topic of wireless technology. The four short videos each have their own focus and the aim is that, together, they can keep young viewers engaged in learning about new STEM topics. The videos are provided below, with links that can be accessed by the public for those interested.

As stated earlier the focusses of each of the videos were as follows:

Video 1: A broad overview of the mod and what it lets you do in-game. The idea of this video is to show the amazing capabilities that radios/wireless technology enable within the virtual Minecraft world, a context that is likely to be familiar to the viewer.

https://drive.google.com/file/d/1vM9zBH4oS4kjWa-442qH59u_L85UskuN/view?usp=sharing

Video 2: A quick set-up guide for building a simple working radio in Minecraft. This hopefully makes the previously shown-off capabilities seem accessible and easy to implement within the Minecraft world. <https://drive.google.com/file/d/1T88CSV9H4HMEL5TtzjKLz2yXtwz-nmpX/view?usp=sharing>

Video 3: An explanation of the user interface for one of the in-game radio's and how to use it to communicate with friends on the same server. This allows viewers to see (and try for themselves if they download the Minecraft mod) a somewhat simplified version of how radios are operated in real life. The goal of this is to give the viewer/player a feeling/idea for how to operate a tool that maybe seemed very complicated or too hard not so long ago.

https://drive.google.com/file/d/10ubX4OXI0d2gmSilh3HUZi4x_UeWLOpk/view?usp=sharing

Video 4: Briefly and simply explains fundamental concepts like frequency, voltage, resistance, and current. This finally makes the direct connection from what the viewer has seen being done in a video game that potentially feels very familiar and fun to them to real and powerful STEM concepts.

https://drive.google.com/file/d/14HCFWHbrSzMEz000U4wCrPwu_jfsgFc4/view?usp=sharing

Activity 2: Direction Finding Activity

Purpose:

Teach students about basic properties of radio signals and how they can be applied in direction-finding activity.

Overview:

Radio signals are all around us. Many modern “wireless” devices use radio transmissions to communicate with networks. Cellular phones communicate with cellular towers. Computers with Wi-Fi networks. GPS receivers get their signals from satellites. Maps are not the only way we can find our location relative to other objects. Direction finding, by locating the direction and distance of a source of radio emissions, is important for finding “bugs” used for spying, tracking criminals by their cellular phone emissions, finding skiers buried by avalanches by their portable radio beacons, and tracking endangered animals wearing radio collars.

In this activity a simplified phase- array antenna is used. The phase-array is a type of directional antenna which compares the phase difference between two antennas. The difference of phase of the two signals can be used to determine the direction of the signal through 180 degrees. If radio waves are thought of as analogous to ocean waves, the crests of the waves can be used to identify the phase of the wave. Two in-phase waves arrive with the crest’s incident on the antenna at the same time. Two out-of-phase waves arrive with crests incident at the same time as troughs. If the signals were simply added together, in-phase waves would have twice the amplitude and the two out-of-phase waves would have zero amplitude. If we measure the phase relationship between the two waves, using two antennas separated by a distance on the scale of the wavelength, we can determine direction. Using two locations for the receiver, we can unambiguously identify the direction of the signal being emitted on the surface of the earth.

A video demonstrating the direction-finding activity can be accessed by the public and is found at the following link for those interested:

<https://drive.google.com/file/d/1vRyGSX55kA91z33ywckErlFHOo2GgZ88/view?usp=sharing>

Grade level 9-12

Time: 1 Class Period

Skills Required:

Mathematics, geometry, trigonometry

Measurement

Materials and Tools:

Phase array kit

Laptop

Pencil and paper analysis

Graph paper, straight edge

Calculator (for sines, tangents)

Preparation:

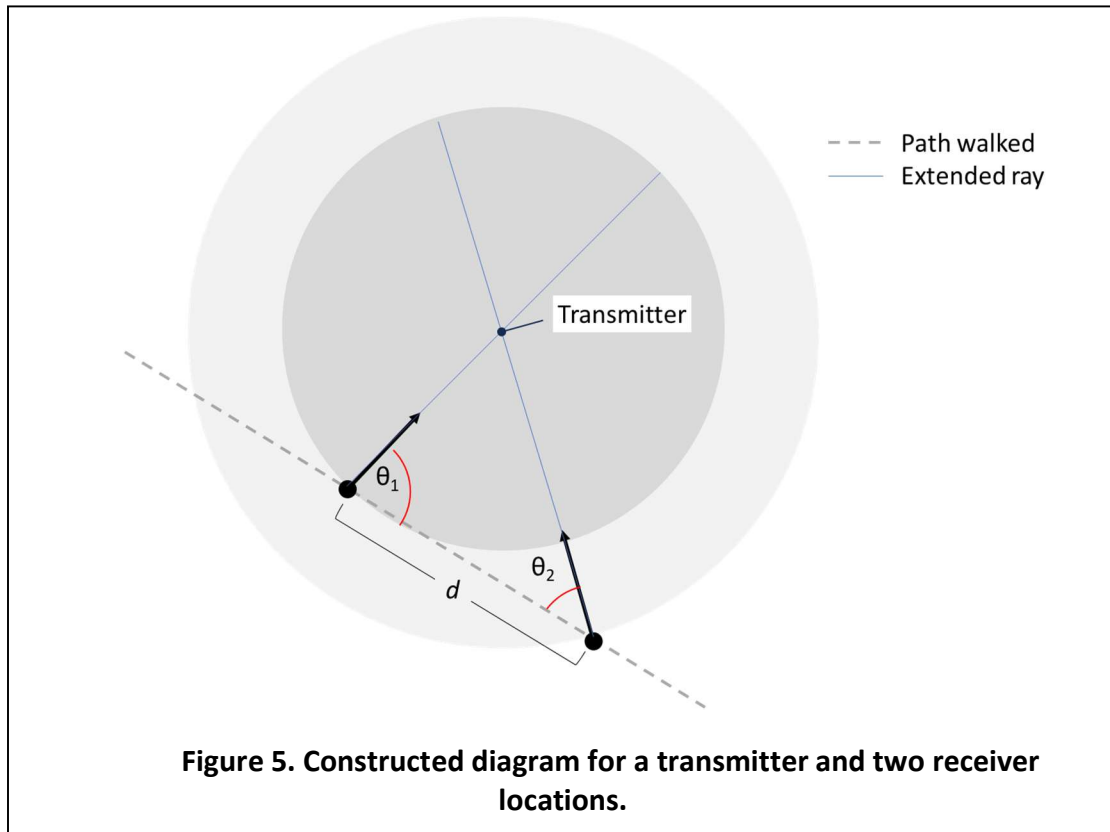
Hide the transmitter inside the classroom and ask students to identify the location of the transmitter using angles and power readings. Construct the apparatus in the following resource (Jon Kraft, 2022).

What To Do and How To Do It:

Hide a transmitter somewhere in the room. Using a direction-finding radio, the students will search for the transmitter. The students will record their position, direction, and power.

Data Analysis:

Using directional antennas such as phase arrays, parabolic reflectors, Yagi antennas or phased arrays, we can tell the relative direction and strength of received signal. If we make two directional measurements separated by a distance (sometimes called a “baseline”), we can triangulate the position of the transmitter. If we also measure the received power, we can estimate the transmitter’s output power in our direction.



This is a geometry problem and can be solved by construction or calculation.

Construction

1. Draw the classroom on a piece of graph paper.
2. Using floor or ceiling tiles identify the path taken and observation points.
3. Draw a straight line between a pair of observations.
4. Note the direction in which the observations were taken.
5. Extend the directions to their intersection.
6. The intersection is the location of the transmitter.

Calculations

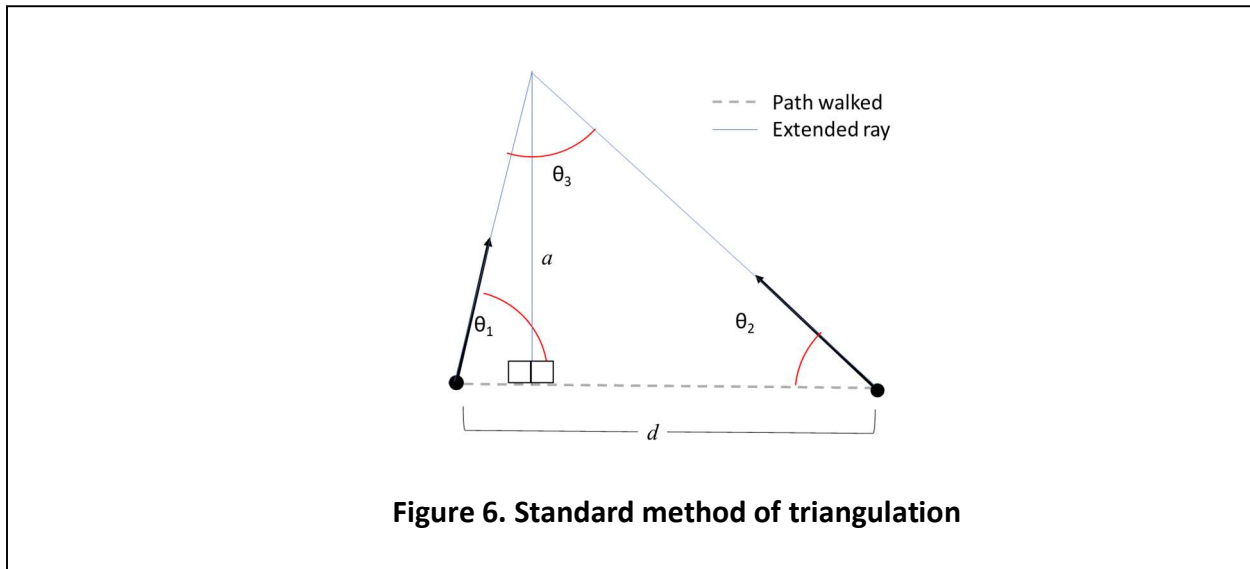
1. Identify the two angles, θ_1 θ_2 , and the distance d .
2. Consider calculating the altitude of the triangle.
3. Calculate the third angle θ_3 at the transmitter.

4. In degrees, the third angle is divided into two parts,
 $\theta_{3,1} = 90 - \theta_1$ and $\theta_{3,2} = 90 - \theta_2$.
5. The base of two right triangles found from these two angles.

$$d_1 = d \sin(\theta_{3,1}) \text{ and } d_2 = d \sin(\theta_{3,2})$$

6. The altitude, or distance to the transmitter, is now found by,

$$\tan(\theta_1) = a/d_1 \text{ or } \tan(\theta_2) = a/d_2$$



Activity Questions:

What other applications can you think of for finding transmitters by triangulation?

How would you calculate distance from the observation points?

Why would we want to record power? Is there a relationship between power and distance?

How do we triangulate GPS satellites? The angles are very small. (Hint: clocks are very accurate, and the speed of light is constant in normal space-time.)

If the transmitter is far away, what are the contributors to errors in calculating the altitude?

How do the formulae change if both angles are on the same side of the altitude?

Using power and 3 observation locations, can you devise a way of using an omnidirectional receiver to triangulate the transmitter? What are the problems with using just 2 observation locations?

Adaptations for Special Needs

The classroom exercise does not need special accommodations for sight or hearing.

Activity 3: Quiz Generator

Purpose:

The overarching goal of the ARRL ham radio courses is to engage students in an active STEM-oriented field where they have everyday experience, whether they realize it or not. The objective of these course materials is to prepare the students to take and pass the ham radio license examination from the Federal Communications Commission (FCC). Along the way, they will engage with topics in Public Safety, Communications, Electrical Engineering, Atmospheric Science, Space Science, Physics, Mathematics and Computer Science. The quiz generator fulfills a part of this goal by introducing the students to all the topics on the exam.

Overview:

The question pool has more than 1400 questions. Every question is categorized by license and topic. The categorization is intended to allow quizzes to roughly follow classroom discussions. Each question is also tagged with a resource indicating where discussions of the question topic can be found. The following objectives should be considered when using the quiz tool,

1. Use quizzes frequently as part of your teaching techniques
2. The number of quiz questions is customizable by the student. Frequent, small quizzes keep the students engaged without providing a classroom burden.
3. Encourage collaboration with fun classroom activities
4. A “Fun-to-try” category is included that can engage students in appropriate classroom activities. The resource link will include an indication of other educational modules that may help teach the topic or recommend inexpensive equipment that can be used as part of a classroom activity. Students should be encouraged to take quizzes with the category “Fun-to-try” and offered opportunities to explore interesting quiz questions on their own.
5. Give helpful feedback on every question in the quiz
6. Feedback is provided at the end of the quiz and in a simple text file that contains the quiz questions, responses, answers, topics for the question and resources. The quizzes are not scored, as our purpose is not to specifically test knowledge but to provide a customized study guide.
7. Make every quiz interesting using different questions
8. Every quiz is unique, questions are drawn at random from the selected question topic and level. The variety of questions and surprises should engage the curiosity of the student.
9. The question pool is provided as a .csv file. Technologically inclined instructors are encouraged to data mine using tables in programs like Microsoft Excel or Google Sheets.

Suitable for grades 5-12.

Useful References:

1. Carpenter, Shana K. "Testing Enhances the Transfer of Learning." *Current Directions in Psychological Science*, vol. 21, no. 5, 2012, pp. 279–83, <https://doi.org/10.1177/0963721412452728>.
2. Roediger, Henry L., III. "Opinion | How Tests Make Us Smarter." *The New York Times*, 18 July 2014, <https://www.nytimes.com/2014/07/20/opinion/sunday/how-tests-make-us-smarter.html>.
3. Romo, Sandra. "Using Quizzes to Measure Teaching Effectiveness: How Do You Measure Up?" *Education World*, 25 Aug. 2010, p. 1, https://www.educationworld.com/a_curr/profdev/profdev180.shtml.
4. Silver, H. Ward, editor. *The ARRL Handbook for Radio Communications 2021*. Ninety-Eighth edition., ARRL, 2020.

Time:

The activity can be conducted in 5 to 10 minutes of class time. Budget 1 to 2 minutes per question.

Skills Required:

- Mathematics
- Recognition of familiar concepts
- Creative problem solving

Materials and Tools:

- A computer running Windows 10 or 11
- Installer for software

Preparation:

Before the quiz, remind the student(s) of your expectations. This may include topic, level, number of questions and special instructions of where the result file is to be stored and or reviewed.

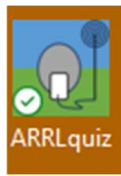
Early quizzes may be taken as part of a 2-person team. This encourages discussion, especially regarding tough questions for which material has not been covered.

Background:

All questions have background material in the ARRL handbook. The handbook is very practical in nature. For some students this may not be the best source material for learning.

What to do and how to do it:

1. Installation
 - 1.1. Choose a folder which all students can access
 - 1.2. Extract the .zip file which was provided to you or you downloaded (Gomez-Haibach, 2024)
 - 1.3. Place the entire contents of the .zip file into the destination folder
2. Running the program



- 2.1. Click on the Ham Radio icon.
- 2.2. The following text will greet you in a terminal as you begin the quiz,

```
Welcome to the WPI Ham Radio Question Databank
The standard licensing exams are 35 questions long. The
exam is taken in the timespan of one hour in front of a licensed proctor.

This quiz uses multiple-choice test questions from the 2022-2027 question databank.
You choose the number and topic of the questions. Some questions may bridge
multiple topics.

Choose an exam level, 1. General, 2. Technician, 3. Extra, 4. All levels
Enter a number for the level.
```

2.3. The tables below explain the choices in more detail.

1	General	The entry level license emphasizing basic radio operation and concepts.
2	Technician	Middle level and emphasizes more advanced radio operation and concepts.
3	Extra	The most advanced and emphasizes electrical engineering and operating conditions.

4	All levels	Does not limit the level of questions. This allows for more exploration of the topics.
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```

1. Communications      2. Electrical Engineering      3. Atmospheric Science
4. Space Science      5. Robotic Engineering        6. Physics      7. Mathematics
8. Computer Science   9. Fun-to-try
X. to exit
Enter a number for the topic.

```

1	Communications	Methods of communication and terminology used in Ham-to-Ham communication.
2	Electrical Engineering	Antenna, electromagnetic wave propagation, circuits and operation of circuits and how to improve operation of communications equipment.
3	Atmospheric Science	How the atmosphere affects radio frequency propagation, with an emphasis on weather phenomena.
4	Space Science	Anything outside the atmosphere, including the moon, comets, meteors, solar flares and communications with satellites.
5	Robotic Engineering	Remote control of programmable machines.
6	Physics	Fundamental phenomena, the "why."
7	Mathematics	Calculations, formulae, and fundamental understanding of mathematical models.
8	Computer Science	Understanding algorithms.
9	Fun-to-try	Classroom-demonstratable projects.
X	eXit	Leave without starting the quiz.

```

Enter the maximum number of quiz questions you want to take:

```

This determines the maximum length of the quiz. The quiz length is also determined by the level and topic.

```

What filename do you want to use to store your results so that you can review?

```

A unique filename should be used. User, time and date are recommended.

2.4. The questions begin after the filename is entered.

```

Q:1      What is QRP operation?
This question's topics: Communications
A -> Remote piloted model control

```

```

B -> Low-power transmit operation
C -> Transmission using Quick Response Protocol
D -> Traffic relay procedure net operation
A B C D X ?

```

The format is typical multiple choice, but “X” provides the opportunity to skip a question.

```

*****Here are your quiz results!*****

Q:1    What is QRP operation?
FCC Q:  G2D10
This question's topics: Communications
A -> Remote piloted model control
B -> Low-power transmit operation
C -> Transmission using Quick Response Protocol
D -> Traffic relay procedure net operation
chosen : X, actual : B
Study the following reference(s): ARRL Handbook

```

Row 1	The number and text of the question.
Row 2	The FCC has assigned a unique identifier to each question. The first letter denotes the license level. The next two characters denote the topic, and the last number denotes the question in the series.
Row 3	We have our own topic categories for pedagogy. Each question may span multiple topics.
Row 4-8	Multiple choice answers. Only one is correct.
Row 9	Chosen and correct answers. If the chosen answer is correct, this is stated.
Row 10	References and guidance for the correct answer to be used as a study guide.

3. Retrieving a completed quiz

3.1. The quiz is stored on the Desktop as a text file.

4. Data mining and customizing the database

4.1. The database can be customized by adding, removing or editing the rows.

4.2. Do not change column order and headings. The python code is sensitive to column order and heading.

Data analysis:

Students should be encouraged to keep a record of quizzes they have taken and chart their progress or performance.

Activity questions:

- Which quiz question would you like to explore further?
- How has your performance improved?
- Have you encountered a practical use of the current quiz questions during the past week/month/year?

Adaptations for special needs:

Visually impaired students may need their typical assistance with operating a computer.

Hearing impaired students will not need accommodations.

Discussion

Activity 1: Minecraft Lesson Videos

When designing our Minecraft Videos, we wanted to ensure that they were short, engaging, and informative. This way, if a viewer who is already interested in Minecraft comes across our videos, they might continue watching the STEM focused parts and get a better understanding of the STEM subjects in the context of Minecraft. In the last video, we try to connect what the viewer saw and learned in the context of Minecraft to real, fundamental STEM concepts. One difficult consideration to keep in mind was the goal of keeping our videos engaging. To do this, we used editing techniques to overlay images, voice audio, and Minecraft gameplay all together so that the viewer never has to engage in a lecture style video section. This meant keeping the action going whether it be overlaid images, animations, or other effects, but making sure not to overdo it.

Activity 2: Direction Finding Activity

When choosing to create the direction-finding activity, we found the hands-on nature of the demonstration crucial. From our successful participation at “Geek is Glam” event and the advantages provided by using amateur radio as an educational tool, we intended to preserve the experimental and exploratory aspects, allowing the activity participants to move the transmitter around (*Amateur Radio in the Classroom*, n.d.). Their influence and changes to the position of the participant directly showed in the demonstration. Additionally, the activity demonstrates an important yet interesting concept in wireless communications, phased array beamforming, in a basic, simplistic manner. The technology shows relevance in today’s wireless communications systems, such as 5G transmitters, satellites, and self-driving cars (Jon Kraft, 2020).

Activity 3: Quiz Generator

There were two directions we considered for this module. One choice was to develop a game where competitive scoring was possible. An example of what to avoid is “Squid Game”, a competitive South Korean game show, where players are eliminated if their score is too low compared to the best players. Multiple choice answers lend themselves well to these competitive game formats. An alternative, a cooperative game, preferred in the educational environment, is difficult to recast from the multiple-choice form. A third alternative, non-scoring, allows the teacher to reformulate the quiz format as either cooperative or competitive. This is our preferred format as the questions require significant study and the reward should be mastery of the material.

A second consideration was the simplicity of setup. A competitive game requires either a leaderboard for serial competitions, or a server-client configuration for parallel play. The leaderboard itself is simple to write code to implement but adds complexity to administration. The server-client configuration requires connectivity, often implemented with socket

communication. The clients need to be able to find the server and maintain a connection. In school environments, this may require the involvement of the Information Technology department. A non-competitive standalone application allows any student to unpack and run the quiz generator locally.

A textual user interface (TUI) was chosen over a graphical user interface (GUI) for simplicity in implementation. The application only needs to respond to a few types of keystrokes which can be handled using a short subroutine. TUIs have many built-in advantages, such as being appropriately sized for limited resolution displays, a scroll back buffer to review previous results/entries and the ability to be well represented by text-to-speech applications for visually impaired users. One example of a text-to-speech application that works in the console is Microsoft Game Bar. (joannaleecy, 2023) The primary disadvantage of the TUI in the game context is the lack of obvious visual feedback on success or failure. This could be overcome by using ANSI escape codes for color. Even with these advantages, the retro look of the console could be a disadvantage. For an expert in GUI, changing the application appearance would be straightforward but does not result in a major functional change.

The quiz report is saved by the student with a filename designated by the student. While this type of file maintenance is not ideal, we are unsure if we want to impose organization or data maintenance. In a more professional application, results could be stored in a permanent database which could be managed by database queries. A second application for teachers would be required to organize or prune the database. The current schema uses Windows File Manager as its management tool.

The overarching goal for the application is simplicity in implementation and obvious usage. Single computer usage allows the teacher to encourage competitive or cooperative games without the Information Technology department's involvement. Contextual clues, such as the TUI, encourage keyboard interaction. Microsoft Windows provides file management tools. Simplicity is a good foundation for learning applications.

Attempted Survey Analysis

Our intent in using the "STEM Semantics Survey" was to collect quantitative data that could be analyzed using statistical methods. However, due to the limited reach of our project, we were not able to acquire a proper sample population that could have been analyzed. In our visit to NEST to collect data, there were only a few responses that could be used for analysis which was not enough for proper analysis.

However, if we had received an adequate number of responses, the data could have been analyzed using paired t-tests. The data could be separated into groups, performing t-tests on pre-survey data versus post-survey data to determine if there would have been a statistically significant difference between pre- and post- survey interests in STEM. Additionally, the results of activities could have been compared against one another using t-tests, to determine which activities were the most effective.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

Overall, our attempts to gather data focused on discussion with the students who regularly attended NEST. Although we attempted to gather as much data as we could, we only received a handful of official responses to the surveys we created to gather information about the students' interest in STEM. This led to our project's focus shifting from directly giving students a new study method into to creating a form of curriculum for them, based on a variety of methods of data collection we feel would be most valuable after our time spent with the students at NEST.

Originally, we wished to use inferential statistics to collect our data. Inferential statistics allow an analyst to take a set of sample data and create understanding of the wider population which the sample pulls from. Our sampling frame (or group the sample drew from) was Massachusetts students from 5 to 13. We planned to take a large sample of students from NEST, separating them into groups and having each group try a different activity (with another group attempting all three), then using their responses to create a wider conclusion on the usefulness of what we had created.

However, we found that the response pool was simply too small to gather enough relevant data. Thus, we began exploring a variety of different research strategies which we feel will be a valid way to measure the impact of our activities in some future project based on our plans.

Before we began our search for new strategies, we used thematic analysis—examining a variety of qualitative data to search for common themes-- to pull what we could from the discussions we had with NEST students. Each student was interested in a different area of STEM; some enjoyed the amateur radio classes taught at NEST, while others were more focused on coding in Python or Bash.

From there, we used our activity sets to begin the process of creating a finalized curriculum, which we hope will continue after our time on this project with other teams of project students. These activities were developed after initial field studies at the 2023 Eastern States Exposition in Springfield, Massachusetts and the Girl Scouts "Geek is Glam" Exposition on the WPI campus. Before creating the activities, we also completed extensive study of the curriculum on the ARRL website and current academic papers on the teaching of STEM. The challenge we have found is overcoming students' perception that STEM fields are difficult to learn, despite their everyday contact with technology. Technology is part of every piece of student life: it is increasingly important that students become comfortable with it.

Our approach focuses on:

- Initial engagement by using short-form videos to mirror current social media formats. These serve to engage primary and secondary school students in amateur radio.

- Providing students with skills and experience, which develops confidence in STEM topics is using the direction-finding activity.
- Retention in STEM fields is enabled by using a quiz generator to help students learn and practice for an amateur radio license to join the global community of radio.

Future Improvements

A strategy for improvements involves the stakeholders: educator associations, educators and most importantly, students. Presenting at educator-related organizations would provide feedback on regional goals and needs at the highest levels. Having a seat within the ARRL Teachers Institute would help deepen our understanding of their initiatives. Meeting with educators one-on-one would help us incorporate what teachers need for their classrooms. Finally, field trials of the educational modules provide independent feedback on what works.

Massachusetts and the reputation of WPI as STEM University can open the doors to participating in education meetings. The Massachusetts STEM Advisory Council has a priority for supporting developing “STEM skills for all through applied learning” and provides state-sponsored funding for educational initiatives. (*Massachusetts STEM Advisory Council | Mass.Gov*, n.d.) WPI is the host for the regional chapter of the Massachusetts STEM Network providing contacts at the chapter level. Another path forward to approaching educational associations would be presenting and gathering contacts at the Massachusetts Teacher STEM Fair. (*Massachusetts Teacher STEM Fair*, n.d.) or the Massachusetts Association of Science Teachers, a branch of the National Science Teachers Association. Further conversations with the WPI STEM Education Center may provide other paths forward for region-level resources for building on the results of this IQP. Success is presenting the work at regional meetings and obtaining funding for an increased focus on this work.

The 24-year-old ARRL Teachers Institute provided funding for the Minecraft mod Radiocraft and for other educational initiatives. Within this tenure they provided resources and training to 650 teachers. Participating in meetings by both listening and presenting this work would help develop the project further and align it better with the goals of the ARRL officers and their mentorship experience.

The interaction with NEST provided useful changes in direction for this project. Further interaction with local schools and individual teachers will allow us to respond more specifically to STEM educational goals within the classroom. Local schools, traditional public, charter and private schools, like the Massachusetts Academy of Math and Science, provide further breadth in social, economic and racial diversity. Professional educators have both academic and practical experience with educational methods and teaching the current generation of younger

students. Without teacher approval, it is unlikely that teaching organizations or teachers will adopt our activities.

Interacting with more students would allow us to develop our own approach which will be targeted towards the current generation's needs in understanding STEM topics. In the future, we would most like to work with a wider range of primary and secondary school students, from ages 5 to 13 across Massachusetts. In this approach we want to capture respondents that are already passionate about STEM and those with less exposure to the subjects. We would give out a pre-survey to our sample students to collect information on their exposure to STEM, along with their enjoyment of the various possible activities, to collect the information relevant to understanding how they would interact with our project.

We believe to be the strongest method of collecting these pre-survey data is to be using an exploratory sequential mixed method design. In this method, a qualitative phase of data collection is completed—speaking with students, understanding their relationship with the study and the context surrounding the data we are taking—before a quantitative phase begins, with more concrete survey data being collected. Analysing the data should include measuring inter-rater reliability, which measures the consistency between multiple observers in data collection, between students. We would then take post-surveys, using quantitative data (such as rating excitement and understanding from 1-7) to create a solid backing of ranking on how our activities function. Outside of quantitative data, we'd also like to use protocol analysis throughout our early discussions with the students. Protocol analysis is a method which trains subjects (in our case, young students) to work through problems verbally; this verbal method would allow student's problem-solving skills and methods to be analyzed in real time. This would give us valuable data on how the students use the activities we give them to learn and explore the world of STEM. Studies in the past have found success with similar “interview” and reflection forms methodology. In this study, researchers asked participants about their enjoyment of the learning experiences (Roberts et al., 2018). We could conduct a similar informal interview approach, asking questions like “Did you enjoy the activities” or “What did you learn from the activities.”

Future work should be kept within the focus, using wireless communications to entice, engage and educate students in STEM. Engagement with the various stakeholders is essential to future success. Below, we have written about improvements to the individual activities, so that our work may be improved upon and used to help more people than we were able to reach during the 2023-2024 academic year.

Activity 1: Minecraft Lesson Videos

In the future, we hope to make these videos more engaging by producing them on a larger scale. Some work that young audiences find engaging includes professional voice acting, animated segments, and filmed gameplay with voiceover. This may allow a stronger engagement from the audience, which would result in a wider viewing range.

Many students find interest in STEM from a young age due to engaging media on the subject (Chen et al., 2023); it would be useful for these videos to have a *story* element, rather than simply being educational. Minecraft, being one of the most popular video games of all time, can be used to our benefit here by leveraging its popularity to create a popular and widespread set of videos.

Activity 2: Direction Finding Activity

Scaling this activity for use in additional classrooms requires additional hardware: antenna assemblies, software defined radios, and laptops. We need to consider whether unassembled kits, completely assembled kits or off-the-shelf components are better for the activity.

Add onto the current activity with more antennas being included into the assembly to further increase the accuracy of the activity. This can serve as a method to improve the understanding of the concept.

Activity 3: Quiz Generator

The Quiz Generator is a proof-of-concept improvement on other amateur radio quiz generators. The purpose is different, providing quick quizzes to help students consolidate or spark new areas of learning. Categorization allows teachers and students to pick lesson-aligned questions more accurately to match their curriculum. The provision for a database field which can provide guidance for where to find more detailed information is also unique. This field needs to be populated with more helpful guidance.

Final Thoughts

These activities have not been evaluated by teachers or potential students. Obtaining feedback from all the interested parties, teachers, students, and amateur radio operators to improve and create new modules is important to improving the activities. New activities can be updated versions of those presented by other sources, including the ARRL, or completely new technologies from the WPI WILab. The success and areas of improvement should be tracked.

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APPENDIX A: PYTHON CODES FOR QUIZ GENERATOR

ARRLTestPoolparser.py

```
import csv
# initialize
BOQ = False # Beginning of Question
EOQ = False # End of Question
question = []
ndx = 0
# ~~ pick one to digest ~~ notice that every 1 to 2 years there is a new question
pool from a Class
#with open("Technician Pool and Syllabus 2022-2026 Public Release March 7
2022.txt","r") as test, \ open("questionDB.txt","w") as output:
#with open("General Class Pool and Syllabus 2023-2027 Public Release April 15
2023.txt","r") as test, \ open("questionDB.txt","w") as output:
with open("Amateur Extra Class Pool and Syllabus 2020-2024 Public Release March 5
2020.txt","r") as test, \ open("questionDB.txt","w") as output:
    database = csv.writer(output, delimiter="\t")
    for line in test:
        line = line.replace("\n","")           # remove newlines at the end of the line
        if len(line) > 5 and EOQ:             # not an unusually short line and the end-
of-question is found
            BOQ = True                         # must be a new question
            EOQ = False                       # reset end of question
            question.append(line)             # add first item in list
        elif len(line) > 5 and BOQ:           # not an unusually sort line and the
question started
            question.append(line)             # add in new answer to list
#        print(line)                          # debug statement
        if line.find("~~") >= 0:             # ~~ is end-of-question marker, -1 if not
found
            print(question)                   # debug statement
            database.writerow(question)       # write list (current question) with \t
delimiters
            BOQ = False                       # reset BOQ
            EOQ = True                       # completed question
            question = []                     # reset list
print(question)                             # debug

# now use excel to import these files, add columns and do some splitting
```

ARRLQuiz.py

```
import pandas as pd # database tool

# Read the csv file into the dataframe. Note that the file must contain headers and
the headers
# must match their usage in this code.
def load_database(level):
```

```

df = pd.read_csv("./ARRL All Question Database.csv",header=0)
match level:
    case 1:
        print("Case 1")
        df = df.loc[df['License Class'] == 'G']
    case 2:
        print("Case 2")
        df = df.loc[df['License Class'] == 'T']
    case 3:
        print("Case 3")
        df = df.loc[df['License Class'] == 'E']
# do any manipulation here
df.fillna(0,inplace=True)
return df

# A short segment of code that pulls the random list with length <= nquestions on the
topic
def choose_quiz_questions(df,topic,nquestions):
    possibleq = df.loc[df.iloc[:,topic-1]==1]
    Q = possibleq.sample(n=nquestions)
    return Q

# Prologue and collect data
# Prologue motivates the quiz format.
# Topics match Professor Radzicki's recommendations
# The number of questions are flexible, and allows it to be short enough to keep
# a student's attention.
# TODO Improvement: request class of license as an additional filter
def start_screen():
    import sys # allows premature exit
    print("Welcome to the WPI Ham Radio Question Databank\n",
        "The standard licensing exams are 35 questions long. The\n",
        "exam is taken in the timespan of one hour in front of a licensed
        proctor.\n\n",
        "This quiz uses multiple-choice test questions from the 2024 question
        databank.\n",
        "You choose the number and topic of the questions. Some questions may
        bridge\n",
        "multiple topics.\n")
    print("\nChoose an exam level, 1. General, 2. Technician, 3. Extra, 4. All
        levels")
    level = None
    while level == None:
        level = input("Enter a number for the level. ")
        if level.upper() == "X":
            sys.exit()
        elif len(level) > 1 or level < "1" or level > "4":
            level = None
    level = int(level)
# topics match column headings in database. This would be better handled with a
dictionary
# that precisely matches the column headings. For the rest of the code, we
handle these by index number.
print("\n1. Communications\t2. Electrical Engineering\t3. Atmospheric Science\n",

```

```

        "4. Space Science\t5. Robotic Engineering\t\t6.Physics\t7. Mathematics\n",
        "8. Computer Science\t9. Fun-to-try\n X. to exit")
topic = None
while topic == None:
    topic = input("Enter a number for the topic. ")
    if topic.upper() == "X":
        sys.exit()
    elif len(topic) > 1 or topic < "1" or topic > "9":
        topic = None
topic = int(topic)
squestions = None
while squestions == None:
    squestions = input("Enter the maximum number of quiz questions you want to
take: ")
    try:
        nquestions = int(squestions)
    except ValueError:
        print("An integer response is required.")
        squestions == None
filename = input("What filename do you want to use to store your results so that
you can review? ")
return topic, nquestions, filename, level

# the quiz mechanism
def ask_questions(Q):
    # allows A B C D answers and X, skipping allowed.
    def get_letter_answer():
        ans = None
        while ans == None:
            ans = input('A B C D X ? ').upper()
            if ans == 'X':
                print('Question skipped')
            elif len(ans) > 1 or ans < 'A' or ans > 'D':
                ans = None
        return ans

    answersgiven = list()
    for ndx in range(len(Q)):
        print(f"\nQ:{ndx+1}\t{Q.iloc[ndx]['Question']}")
        qtopic = list()
        for jdx in range(11): # this is the column index of the topics
            if Q.iloc[ndx,jdx]==1:
                qtopic.append(Q.columns[jdx])
        print(f"This question\'s topics: {' '.join(qtopic)}")
        print(f"A -> {Q.iloc[ndx]['Choice A']}")
        print(f"B -> {Q.iloc[ndx]['Choice B']}")
        print(f"C -> {Q.iloc[ndx]['Choice C']}")
        print(f"D -> {Q.iloc[ndx]['Choice D']}")
        answersgiven.append(get_letter_answer())
    return answersgiven

# this interface provides the student with feedback on how to improve their knowledge
using on the 'Response'

```

```

# column of the database. A better, but much more involved way, is to supply a
# response for the
# student's specific answer.
def result_summary(Q,A,filename):
    print("\n") # insert blanking lines to separate from quiz
    output = list() # where we store the output as we are both displaying and saving
        to a file
    output.append('*****Here are your quiz results!*****')
    for ndx in range(len(Q)): # loop through questions
        output.append(f"\nQ:{ndx+1}\t{Q.iloc[ndx]['Question']}") # the question
            itself
        output.append(f"FCC Q:\t{Q.iloc[ndx]['Question Identifier']}") # the FCC
            database identifier
        qtopic = list()
        # list all topics relevant to the question
        for jdx in range(11): # this is the column index of the topics
            if Q.iloc[ndx,jdx]==1: # could be 'True', but we chose 1
                qtopic.append(Q.columns[jdx])
        output.append(f"This question\'s topics: {' , '.join(qtopic)}")
        output.append(f"A -> {Q.iloc[ndx]['Choice A']}")
        output.append(f"B -> {Q.iloc[ndx]['Choice B']}")
        output.append(f"C -> {Q.iloc[ndx]['Choice C']}")
        output.append(f"D -> {Q.iloc[ndx]['Choice D']}")
        if Q.iloc[ndx]['Answer'] in A[ndx]: # identify whether the question was
            correctly answered
            output.append(f"Answer {A[ndx]} is correct!")
        else:
            output.append(f"chosen : {A[ndx]}, actual : {Q.iloc[ndx]['Answer']}")
            output.append(f"Study the following reference(s):
{Q.iloc[ndx]['Response']}")
            # Response can encode interesting trivia too. Use '\n' to encode line
            breaks in
            # the response string.
    print("\n".join(output))
    with open(filename+".txt",'w') as file:
        file.write("\n".join(output))

# maybe you like some of the functions above, but don't like the terminal user
# interface (TUI)?
if __name__ == "__main__":
    topic, nquestions, filename, level = start_screen() # Ask some questions of the
        user to set up the quiz
        # TODO ^ improve by creating a dictionary with user data
    quizdf = load_database(level) # ingest csv file (Excel export) and return a
        dataframe from Pandas
        # TODO ^ improve by adding image import into dataframe
    questions = choose_quiz_questions(quizdf,topic,nquestions) # take the user input
        and select quiz questions
    answersgiven = ask_questions(questions) # present the questions and collect
        responses
    result_summary(questions,answersgiven,filename) # study guide based on results

```

APPENDIX B: MINECRAFT VIDEO SCRIPTS

Video #1 - Mod Overview:

Hello everyone! We are the Ham Radio Interactive Qualifying Project representing Worcester Polytechnic Institute. I know that's a lot of words, so let's break down what that means. Worcester Polytechnic Institute is an engineering school in Massachusetts; we complete a course called an Interactive Qualifying Project which has us study real-world problems and create solutions. With this video series, along with the rest of our project, we hope to get the word out about the world of ham radio and help make engineering and technology more accessible for younger audiences.

Amateur Radio-- also known as ham radio--is a hobby that people around the world engage in. It allows people to communicate across long distances using physical radios, a method which has become less common due to the invention of cell phones and online communication.

It's a very cool interest which connects people and allows a new way to communicate, no matter how close or far someone may be or if they have internet or not. One of the most important examples of the real-world usage of ham radio is communication in major emergencies such as a natural disaster, where people may not have access to more modern communicative devices. ham radio is also useful to understand how to work with the technology used to create antennas, satellites, and much more.

As I mentioned, we're a student group working on a project to engage kids in STEM-- Science, Technology, Engineering, and Math. Since a lot of students tend to shy away from traditional textbook-style learning of these complicated topics, we want to engage with students on their own playing field: through the video game Minecraft. While this series is aimed at kids, please note that parents and children alike can watch this together and learn.

This first video will serve as a quick introduction to the Radiocraft mod in Minecraft. Radiocraft is a mod or "modification"-- a program which allows the addition of things not included in the basic Minecraft game. Radiocraft, of course, inserts the ability to create and use amateur radios in the game. This allows faster player communication and a more interesting set of builds for experienced players. The mod was created by Lucas (callsign W1BTR), who along with a fantastic team of designers and programmers are working hard to make this mod a reality. There are many cool pieces of this mod, the most impressive of which is custom-designed radio pieces that players can use to build these machines.

This piece of equipment can be crafted with wire and several materials which are included in the basic Minecraft world. This will allow players to use their existing Minecraft expertise to begin to foray into this new part of the game. The rest of the videos in this series will focus on different materials to work with in this version of the game. We look forward to seeing you throughout the rest of our series!

Video #2 - Making Your First Radio:

Hello all, we are the Ham Radio Interactive Qualifying Project representing Worcester Polytechnic Institute. We hope to engage students using the video game Minecraft, using a game modifier known as Radiocraft as an educational tool to further younger watchers' understanding of ham radio and the general study of science, technology, and engineering. Don't know what ham radio is? Check out the first video in our series. Lastly, please note that parents and children alike can watch this learn together. Okay, let's get started!

As with almost everything in engineering, this mod's most basic step is creating some wire. You can do so using three pieces of smelted iron ore— from here, the entirety of Radiocraft's designs are at your fingertips. The first item we would like to showcase is the HF circuit board.

Note that "HF" stands for High Frequency. Now, that might not mean anything to you— but before we can explain frequency, we've gotta talk about radio waves. All sound is made up of vibrations: they move through the air from whatever creates the sound into our ears. Radio waves are a bit like that— they're those same vibrations which transport across long distances to connect people from far away. The person speaking into the radio is *transmitting* the radio's signal, and the person who's listening is *receiving* the radio's signal. Frequency represents the number of cycles per second a radio wave transmits. The longer the length of the wave, the smaller the frequency is. That means that lower frequency radios (weirdly enough) transmit further than high frequency radios. This is why many beginner radios (called VHF, or Very High Frequency, radios) transmit *higher frequency* signals than more professional radios— because they can transmit over short distances. Okay, does that make sense? Great. So the HF— high frequency— circuit board will, in-game, allow you to make a high-frequency radio, which you now understand!

Of course, the circuit board doesn't make a radio all by itself. The second item up we would like to showcase is the radio crystal. As silly as it might seem that the game's radios are partially powered by crystals, this item does have historical backing! Radios in the past often used actual crystals to control their frequency. Crystals were largely replaced by new inventions such as the vacuum tube as time went on— and eventually, the vacuum tube was then taken over by the transistor. Cool! Let's keep going.

The third item we need is the radio speaker. In almost all ham radio, there is some form of speaker to help the sound be clear to the listener— just like your computer or iPad has a speaker so you can listen to these videos!

The fourth item we need is a large battery. Batteries are used throughout many, many electronics. They help provide consistent power to devices, and in this case, our radio, using electricity. You might see one in your TV remote, or a toy car.

The second to last item we need is the wire. Wires have many, many real world applications; they allow electricity to travel through them into different electronics. For this example, we'll just be showing it for connecting our power source— the battery— to the radio.

The last item we need is, of course, our radio! This is a 10m HF radio. In the game, that means this radio has a range of over 900 blocks. If you are curious– Minecraft uses the metric system, and therefore 1 block = 1 meter. Therefore, the radio has a range of 900 meters. To make a radio in Minecraft, what you need to do is get these blocks, just like we've been showing you.

The first thing you need for any radio in game or in real life is a power source. For this, we're going to use a battery. If you are working with electricity in real life, you've got to be careful: it can be dangerous when you're first learning how it works. Make sure one of your grown-ups can help you if you'd like to learn more about battery power. When you connect this battery to the radio block, you get a powered radio. But this radio still needs some way to send out and receive radio waves. For this we'll place some antenna blocks and connect them to the radio; antennas in this game, just like in real life, allow us to transmit radio waves.

Now you've got a fully functioning radio that you can use to talk with your friends in Minecraft! To learn how to use it, follow along with our next video. Thanks for watching!

Video #3- How to use your radio (with real life examples!):

Hello all, we are the Ham Radio Interactive Qualifying Project representing Worcester Polytechnic Institute. We hope to engage students using the video game Minecraft, using a game modifier known as Radiocraft as an educational tool to further younger watchers' understanding of ham radio and the general study of science, technology, and engineering. Don't know what ham radio is? Check out the first video in our series. Lastly, please note that parents and children alike can watch this learn together.

Now that you have your very first radio built in Minecraft, you can start using it. If you go to your radio and right click on it, it will bring up the controls that allow you to use the radio. The most important controls are the frequency selector, the mode selectors, and the Push to Talk button. These let you choose who you want to talk to, how you want to communicate, and when you want to talk. Now, if two radios are built in Minecraft from a certain distance, and you and a friend tune both radios to the same frequency, you'll be able to hear them in-game through your radio– just like you would in real life!

All you must do is turn your radio on, tune the frequency, click the button labeled SSB so it is lit up, and hold down the PTT (or Push to Talk) button while you say what you want to communicate to your friend. Your friend can then turn on their radio, tune their frequency, and hear you! Typically, in Minecraft, the method with which players communicate is through simple text messages. However, with Radiocraft, speaking to other players makes communication much easier. Please note that you must play either on the same world or the same server to communicate with your friend. Radiocraft provides a free server for players to communicate over so long as they have the mod [Show IP address on screen]. Such is the IP address on screen.

In real life, hams—users of ham radio—can communicate to others from miles and miles away. A very common instance of hams meeting and communicating is the ARRL Field Day—where more than 35,000 hams come out and communicate with each other. While a lot of communication of the past has been replaced by other communication devices such as cell phones and the internet, ham radio is still being used by many around the United States and the rest of the world.

You may be wondering why these radios are controlled like they are in the Minecraft mod. They were modeled after real-life radios. The PTT, or Push to Talk, function is very common in radio communication. The PTT is usually a button that, upon clicking, will have your voice transmitted through a microphone to the other end. This is very similar to how walkie talkies work, which are still a popular toy to this day. Real life radio seems daunting to learn, but they are very easy to learn about. Just like in Minecraft, if you have a power source, tune your frequency, and push the push-to-talk button, you can talk to people all around the real world. So don't be afraid to use the knowledge you've gained from these videos and Minecraft in the real world! To see some of the concepts that make this wireless communication technology work in the real world, watch the next video entitled "Underlying Concepts."

Video #4 - Underlying Concepts:

Hello all, we are the Ham Radio Interactive Qualifying Project representing Worcester Polytechnic Institute. We hope to engage students using the video game Minecraft, using a game modifier known as Radiocraft as an educational tool to further younger watchers' understanding of ham radio and the general study of science, technology, and engineering. Don't know what ham radio is? Check out the first video in our series. Lastly, please note that parents and children alike can watch this learn together.

One of the most important concepts to understand that makes these radios work, is frequency. Radios work by varying an electrical signal up and down as shown here [show a dot or something representing a signal output moving up and down]. Frequency is just how fast this moves up and down. If it moves faster [show it moving faster], we say that it has a higher frequency. If it moves slower [show it moving slower], we say that it has a lower frequency. Radios can detect different frequency ranges and, depending on how fast the wave is, can decode data like voice or morse code.

The way any electrical signal is produced is by varying voltage levels. When talking about electricity there are three fundamental concepts to understand: voltage, current, and resistance. You can think of electricity as very tiny particles. These particles are called electrons.

When we talk about voltage (measured in volts), we can think of it similarly to how water particles are pushed through a pipe by gravity. The gravitational force would be like the voltage shown in the image: Voltage involves pressure, and in the pipe example, the charged electrons are pushed down through the pipe.

When we talk about current (measured in amperage), we can think of the amount of water flowing through the pipe from the tank as current. In our water example, the current would be how big the pipe is. When we decrease the amperage with the same gravitational force, not as many electrons can escape from the pipe.

Finally, when we talk about electrical resistance, we are talking about how much the movement of the tiny electrons is resisted as they flow through the wire. In our water example, this can be shown by decreasing the pipe width. The pipe with more resistance means that the water has a harder time getting through the pipe. All of these concepts are fundamental to how every electronic device works, including ham radios! We hope this has been entertaining and educational.