A Making and Gaming Approach to Learning About RF Path Loss and Antenna Design

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***Abstract* - As part of an ongoing, longitudinal study on the use of "making" and "gaming" in the classroom, two sequential activities for learning about radio-frequency (RF) path loss and antenna design are presented. "Making" involves integration of makerspace concepts and tinkering in the curriculum, while "gaming" refers to gamified curricula; in this study we investigate the joint use of these two elements in the classroom. The RF path loss activity is modeled after ham radio "fox hunting", where students must locate a transmitter hidden on campus; it makes use of low-cost software-defined radios, and prompts students to confront concepts including measuring signal power, frequency domain thinking, and antenna polarization. The follow-up activity challenges students to build an antenna designed to receive household gas meter readings; students must design their antennas specifically for operation in the 900 MHz band, and must give a presentation describing the theory of their antenna to their peers. A competition is held where students attempt to see which of their antennas can collect the most wireless gas meter readings over a five-minute interval. Assessment data from the broader study show that relative to a baseline offering, the treatment group developed an improvement in interest, perception, independence, and self-assessed abilities. This paper discusses the implementation of the activities, the students' approach to solving the proposed challenges, the assessment data, lessons learned from student focus groups, and instructor observations.**

Index Terms - Antennas, gamification, making, path loss, radios, tinkering.

INTRODUCTION

Two active learning approaches which have recently attracted attention include *making and tinkering* (M&T) [1]–[5] and *gamification* [6]–[9]. These two approaches are distinct within the educational research community, yet they work together naturally in settings such as local hackathons, drone competitions, and robotics competitions. Such events appeal to a wide age range from grades K-12 and beyond, regularly feature industry participation, have high public interest, and are scalable [10]. While M&T and gamification have been studied independently [1]–[9], to the best of our knowledge no formal research has been done on the efficacy of the combination of these two complementary approaches.

M&T is an active learning paradigm that encourages students to ask questions, reflect on past topics, frame problems in the context of projects, and make design choices based upon both instructor-provided and self-imposed constraints. It emphasizes self-expression, personal investment, iterative design processes, and aims to supports learners as decision-makers by valuing creative exploration above the assembly of a final product. M&T also provides unique opportunities to test implementation skills, which can be neglected in a solely lecture-based curriculum. This methodology aims to produce intrinsic self-driven learning motivation rather than purely extrinsic motivation typically seen from traditional, "chalk and talk" educational methods [11]. While some scholars differentiate "making" from "tinkering" (for example, by describing tinkering as a type of making [12]), we will refer to M&T as a unit due to their emphasis on similar goals and tactics (as in [13]).

Gamification is a distinct but related active learning pedagogy of increasing interest to educational researchers that describes the use of game elements in non-game settings to improve learning, motivation, enjoyment, teamwork, and other desirable characteristics. In this paper the term will be used to refer to the overlapping disciplines of game-based learning (GBL) and serious games, and thus includes any learning activity with gaming elements. Gamification has been proposed and outlined by a number of researchers and educators as a means of increasing student engagement, which has been shown to be a "meaningful proxy" for measuring the quality of instruction imparted to the learner in higher education settings [14].

A three-year longitudinal study is currently being conducted to investigate the combined use of these two implementation-oriented approaches in the electrical engineering programs at Western Washington University (WWU, undergraduate-only) and the Air Force Institute of Technology (AFIT, graduate-only) [11], [15], [16]. The program at WWU requires students to complete a junior-level laboratory-based course called "EE 361: Signal Propagation" which focuses on signal transmission through guided media (e.g. classical transmission lines) as well as through unguided media (e.g. wireless transmission in free space). Here, we present two sequential learning activities that demonstrate how M&T and gamification were successfully integrated into EE 361. In the sequel, we present assessment data in the form of pre/post-survey results from baseline and treatment groups, as well as results from a focus group.

FIRST ACTIVITY: RF PATH LOSS

I. Motivation and Learning Objectives

The RF path loss activity is designed to familiarize students with unguided transmission topics such as received signal power and RF path loss through free space. It first establishes how these quantities can be determined experimentally, and then requires the students to apply their knowledge in a class-wide competition to find a transmitter hidden somewhere on campus. Similar activities are well-known in the ham radio community as “fox hunting” and are used by enthusiasts as a test of their radio direction-finding skills; moreover, a similar exercise has been used at the U.S. Air Force Academy [17] to let students test antenna designs by locating a hidden transmitter.

In the first section of the lab, students are provided with an RTL-SDR software-defined radio capable of receiving a wide range of radio signals and functioning as a low-cost spectrum analyzer. With this tool and accompanying software, the students are prompted to develop their understanding of unguided communications by examining various signals and tinkering with reception parameters such as RF gain and band type. By examining diverse signals, students ideally develop an intuitive understanding of the relationship between these signals and the parameters that help characterize and define them. For example, comparison between the signal-to-noise ratios (SNRs) of relatively weak and strong FM broadcasts helps explain audible differences in audio quality of the two transmissions. It also demonstrates the extent to which the strength of the signal compared to noise affects reception quality.

After developing and practicing their own methodologies for analyzing measured signals, pairs of students are challenged to test their new skills in a class competition to find a hidden transmitter. By collecting signal strength data at various locations around the campus, the students use rudimentary triangulation to identify the secret location. As they approach the hidden transmitter (the “fox”), the measured signal power is expected to increase due to the decreasing distance between the fox and reception antenna. The second part of the activity prompts students to test whether the attenuation of a signal in free space truly increases proportionally to the square of the distance from the transmitter. With this knowledge, students can pinpoint the fox’s location by using both the theoretical knowledge obtained in lectures and the practical data collection techniques from the beginning of the activity.

II. Materials

The materials given to each pair of students included: an RTL-SDR with whip antenna and a laptop computer running the freely available SDRSharp software [18]. The RTL-SDR is a $20 USB dongle based on a chip originally intended for digital television reception but adapted by hobbyists for use as a software-defined radio; repurposing an object or device in this manner is a common element in M&T. In addition, a basic whip antenna was provided for use with the RTL-SDR to receive signals that are subsequently displayed with the SDRSharp software.

A low-cost automated fox transmitter for operation by the (ham-licensed) instructor was developed using off-the-shelf components. Because the transmitter must comply with FCC regulations, the instructor or TA must have a Technician ham radio license, and the transmitter must announce its callsign at appropriate times. The Technician license exam covers many of the same topics as EE 361, and as such past TA’s have easily obtained the required license. The materials needed to construct the fox transmitter cost less than $100 in total and included the following parts: a Raspberry Pi 2, a Zilu Rechargeable Battery, a Baofeng UV-5R handheld radio, a simple MOSFET circuit on a breadboard, and a 3D-printed case. A deconstructed view of the fox with the components exposed is shown in Figure I.

FIGURE I
FOX COMPONENTS

The case was produced with a Lulzbot Taz 3D printer, Autodesk’s 123D Design designer, and the Cura Lulzbot splicer. Specifics of the automated fox design and other details pertaining to this activity can be found on the project website [19]; the fox design is open-source, and both the Raspberry Pi code and STL code for the 3D-printed case are provided. The fully assembled fox is shown in Figure II.

III. Implementation

To combine M&T and gamification elements, the foxhunt activity requires students to use skills acquired experimentally during the first part of the activity in a game-like competition. One 110-minute lab session was used for each part of the activity. The first lab session tasked students with learning about unguided transmission topics and developing analysis skills by examining various types of signals throughout the RF spectrum. These included narrow and broad bandwidth signals, analog and digital signals, and

FIGURE II
FOX IN THE FIELD

strong and weak received power signals. In the process, students experimented with the provided materials to find the most effective way to measure and record the signal power at multiple locations, a skill critical for the completion of the second portion of the activity involving the foxhunt.

The second 110-minute lab session was wholly dedicated to the foxhunt challenge. The students were told that the fox was hidden somewhere on campus and they could work in pairs, but it was up to them to find the fox by taking signal measurements at different locations. The first group to find the fox would be given a small prize to maintain the competitive nature of the foxhunt. The students were also required to collect at least 10 received signal power data points during the lab session and label them on a provided campus map. After the location of the transmitter was revealed or discovered, these 10 points were then used to compare the measured, experimental pathloss with the theoretical free-space path loss (i.e., a simple model where received signal power is related to the inverse square of the transmission distance). Figure III shows a map of these relative signal power measurements at various locations recorded by a student during the activity.

IV. Observations

By exploring common signal propagation topics in an informal cooperative setting, the students had the opportunity to test out various techniques and formulate their own understanding of core concepts that the instructor would later teach formally. Allowing the students to learn to operate the measuring tools and use their own techniques for finding the fox puts them in charge of their learning experience. This can benefit both the students and instructor, as the students often become more engaged in lectures if they have already had a chance to discover those skills on their own.

Along with prompting students to employ problem solving and analysis skills, the foxhunt seemed to be an engaging activity for students, as evidenced by their interest and enthusiasm in completing the activity. By using gamification elements such as competition between peers and collaborative group work, the students were engaged, resulting in an active learning environment which may improve upon traditional lectures for many learners [20].

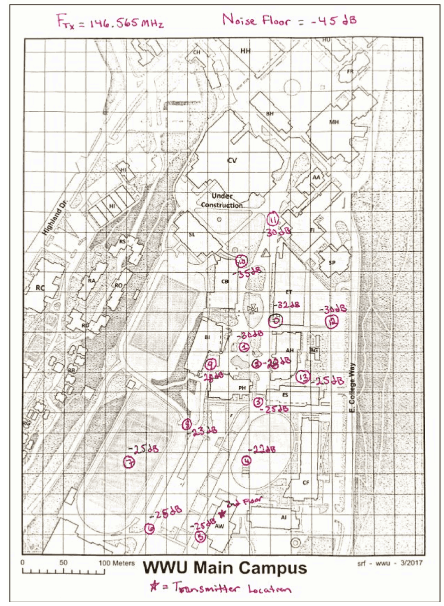

FIGURE III
EXAMPLE RECEIVED SIGNAL STRENGTHS RECORDED ON MAP

One issue surrounding the data collection may merit revision to the activity in the future. To increase their chances of winning the prize (or, equivalently, to decrease the time required to find the fox), some groups initially adopted a rapid "hot or cold" approach to find the fox as quickly as possible, and they postponed formal data point collection until *after* they had located the fox. This led to an unfair advantage for students who waited to formally collect data by giving them a better chance of receiving the first-place prize. One possible remedy could include a requirement that students collect 10 data points before being formally "discovering" the fox, and a teaching assistant could be stationed near the fox so they can check off data point collections of teams that find the fox. Another issue that arose was that, near to the fox transmitter, students observed saturation of the RTL-SDR and therefore could not accurately measure the received signal power; this issue could be resolved by better scaffolding that informed students of this possibility, along with a suggestion of turning down the gain on the frontend of the RTL-SDR receiver. Other "practical" issues arose from uncontrollable behaviors of the system. In lectures, signals were often presented in the context of ideal communication systems without reflections; such reflections induce multipath that results in a more complicated signal propagation model than the simple free-space path loss model. Nevertheless, most students found the activity effective in exercising their pragmatic skills by collecting relevant data and using it to compute signal parameters and characteristics.

SECOND ACTIVITY: ANTENNA DESIGN

I. Motivation and Learning Objectives

As a follow-up activity to the RF path loss/foxhunt lab, the students were asked to design an antenna using knowledge gained from both lectures and outside research. Using their antenna designs, the students participated in another class-wide competition and delivered presentations to their peers to share the practical and theoretical details about their antennas. This activity was designed to have students work in small groups to emulate makerspaces by defining their own constraints and solutions. In the interest of having diverse designs (i.e., to maximize the breadth of knowledge during the "sharing" portion of the activity), at most two of the same type of antennas (e.g., biquad) were allowed to be constructed within the class. In the event of a conflict with multiple teams wanting to build the same antenna, a first-come, first-served approach was used to decide. However, variations on a base structure design, such as biquad antennas and omnidirectional biquad antennas, were permitted. Beyond this constraint, the students were given the design goal of constructing an antenna to effectively receive and decode household gas meter usage data transmissions in the City of Bellingham which use a carrier frequency of 915 MHz. This exercise was developed with the goal of connecting lectures with a real-world application. In the classroom, students were guided through the fundamental working concepts of antenna behavior supported by the knowledge gained from the path loss activity described in the previous section. This second activity aimed to help students develop a better understanding of antenna theory, including physical parameters, design, behavior, and testing.

II. Materials

The materials needed for antenna construction varied, as each group pursued a different design. However, all students were provided with coaxial cable, BNC connectors, an RTL-SDR dongle, a BNC-MCX adapter, and a laptop running the freely-available *rtlamr* meter-decoding software [21] and SDRSharp [18]. In addition, an RF signal generator was available in the lab for testing. Students were encouraged to use household items in the construction of their antennas, though many chose to purchase supplies (particularly highly conductive copper) at local hardware stores.

The equipment from the RF path loss lab was reused in this activity to connect the antennas to laptops. The BNC connectors on the students' antennas were connected to the RTL-SDR devices with BNC-MCX adapters. SDRSharp was used for measuring the beam width and radiation pattern of the antenna. To find the radiation pattern, the antenna must measure a constant, known signal with a controlled frequency and point of origin. For this, an RF frequency generator was used to emit a low power signal within the desired frequency band, noting that compliance with the FCC's regulations on the transmission in that band must be accounted for. The freely-available *rtlamr* software was designed to decode gas meters using the ERT wireless standard employed by household gas meters in the City of Bellingham, so this software was instrumental in facilitating the gas meter signal reception challenge; it decoded the gas meter signals from local households in neighborhoods surrounding campus, displayed the meter ID, a timestamp, and other information.

III. Implementation

Core aspects from both M&T and gamification were employed in this activity. The exercise encouraged students to adopt self-driven processes common in M&T-driven makerspace environments as well as collaboration and competition elements which are prominent features of gamification. As previously noted, the activity began with separating the class into small groups to define the competition teams. Team play is a mechanic that is highly popular in most forms of gaming because of its potential for engaging students. In the context of this activity, the group identification can be used to promote team appraisal and promote productivity and success. The mechanic of group play may also have positive effects outside the academic realm, as the collaborative work style mimics the group dynamic of a hypothetical engineering team. This type of mechanic develops and reinforces communication skills and interpersonal skills which may otherwise be difficult to incorporate naturally.

The hands-on experience of this activity was spread over three weeks to permit sufficient time for background research, antenna construction, and testing. The first week was orchestrated to give students time to research antenna parameters and designs appropriate for the desired frequency range. Students were encouraged to use online resources such as an optional course textbook, IEEE Xplore, and the university library to further develop their knowledge of antenna theory before selecting their designs. The students were expected to develop a basic understanding of the following antenna concepts: radiation patterns, reciprocity, polarization, near vs. far field, bandwidth, and gain. Ultimately this process was student-driven with little influence by the instructor on design selection.

After selecting a design, the groups held multiple building and testing sessions prior to the competition. Coaxial cable and BNC connectors were supplied for the antenna construction; however, any extra materials were left to the students to acquire. After constructing their antennas, students were tasked with measuring relevant parameters (such as radiation pattern), which could be obtained by measuring received signal power of a frequency at various azimuthal and elevation angles. This data collection was implemented to support two aspects: by collecting data, students could verify correct operation of their antenna; and secondly, it provided an opportunity to connect theoretical knowledge to a tangible application.

The competition at the end of the activity involved the entire class and challenged groups to compete to collect the most gas meter readings within a 5-minute interval. As a reward, the top two groups received a small amount of extra credit on the assignment. Finally, all student teams gave a 12-minute presentation where they shared the motivation behind their design choices, the basic theory of operation of their chosen antenna, a discussion of its measured performance, and a Q&A session. Students in the audience were required to ask a least one question, and to conduct a peer-critique of each presentation; as such, each student group received an evaluation from all members of the class.

IV. Observations

The most immediate qualitative observation was that most students seemed to enjoy the project, as this was mentioned numerous times in the end-of-course evaluations. Figure IV shows the student competition in action.

FIGURE IV
GAS METER SIGNAL RECEPTION ANTENNA CHALLENGE

The competitive element of this activity naturally fit into the design, since the activity utilizes group play. Forms of competition are present in most games and can even be included in games that do not inherently contain competition to increase motivation and engagement [22]. Here, the lab activity replaced the typical game and used competition to motivate and encourage engagement by offering a potential reward. Additionally, tasking students with building a physical device made the activity suitable for M&T strategies, particularly by allowing students to explore ideas and solutions with little guidance. This left students as the main decision-makers and ultimately allowed them to fail and succeed by themselves. Whether or not the students' designs were successful, the opportunity allowed them to consider the reasons behind what worked and what did not. This further allowed an iterative design process to unfold, again mirroring makerspace environments.

Another key idea drawn from M&T is offering students the freedom to work with various materials and equipment that they are not typically presented with (e.g., such as household materials). During the construction process, groups had to use supplies that are not typically found in electrical engineering labs, and in some cases, they needed to learn new tools such as drill presses, soldering irons, hand saws, heating torches, 3D printers, etc. to physically construct their antennas. Many of these tools are not formally introduced in electrical engineering courses offered at Western Washington University. Therefore, like a makerspace environment, this activity expanded the students' knowledge about the subject while equipping them with practical new skills.

Though the quality of construction and the performance varied widely between groups, all students succeeded in building functional antennas that could receive gas meter readings. While most students opted to use household materials or materials from the local hardware store, other students used more advanced methods such as 3D printers to construct antennas like the ones shown in Figure V. In the future, we will likely add a cost constraint to prevent groups from spending more money to gain an advantage.

FIGURE V
EXAMPLE STUDENT ANTENNA DESIGNS

In their lab reports, some students reported functional abnormalities in measured radiation patterns when compared to theoretical patterns. While this could be partially due to construction quality of the antenna, it was very likely also due to the testing environment. The students did not have access to optimal testing conditions like an anechoic chamber and were thus limited to the lab rooms which likely introduced severe multipath interference. This observation led to redevelopment of test conditions utilizing an Open Area Test Site (OATS) which will be used in the next implementation of this activity. While still not an ideal testing environment, the use of an OATS will permit students to take signal measurements with reduced reflections, which in turn provide a more accurate radiation pattern generation and signal reception test [23].

In conclusion, designing an antenna for a specific range of operating frequencies provided a culminating design experience, requiring the students to apply their conceptual knowledge of topics such as unguided signal transmission and signal power transfer along with practical knowledge gained from previous labs. In the design of their antennas, the students were confronted with making decisions that balanced such factors such as antenna directionality, available materials, ease/cost of construction, and the activity truly put the students in charge of their own design.

EVALUATION

In this section we present and discuss survey results from a baseline version of the course offered in Spring 2016 alongside survey results and focus group results from the treatment version of the course offered in Spring 2017. Because multiple interventions (i.e., numerous other M&T and gaming activities) were added to the course, the results do not allow us to isolate the effects of the RF path loss and antenna design activities on learning objectives. However, the results provided here are a first step toward assessing the broader impact of M&T and gaming activities, including the two activities described in this paper.

I. Pre/post survey

Table I shows student survey responses from the baseline and treatment courses, which included both a "pre" survey at the start of the course, and a "post" survey at the end of the course. There were four categories of questions: student interest in the subject matter, perception of its value or significance, abilities at various tasks, and level of independence at various tasks. Multiple questions were averaged within each category. The full survey instrument is available at [19]. The goal of the treatment activities was to promote growth in each category as well as an increase over the baseline offerings.

TABLE I

STUDENT SURVEYS FROM EE 361. 23/23 RESPONDED ON THE BASELINE PRE-ASSESSMENT, 22/23 RESPONDED ON THE BASELINE POST-ASSESSMENT, 24/24 RESPONDED ON THE TREATMENT PRE-ASSESSMENT, AND 22/24 RESPONDED ON THE TREATMENT POST-ASSESSMENT

	interest (1-5)	perception (1-5)	ability (1-5)	independence (0-100)
baseline pre	3.96	4.01	2.17	67.4
baseline post	4.06	4.25	3.87	76.6
baseline change	0.10	0.24	1.69	9.2
treatment pre	4.05	4.14	2.13	69.8
treatment post	4.28	4.49	3.98	80.8
treatment change	0.23	0.35	1.85	11.0

The most significant result is in the growth of the "abilities" category, which increased the most in both the baseline and treatment years. With the already high level of growth in the baseline offering, it is perhaps not surprising that the treatment offering did not exhibit significant additional growth.

All four of the categories exhibited some improvement in the treatment year relative to the baseline offering. While the treatment group started with slightly higher "interest", "perception", and "independence" – and slightly lower sense of "ability" – the relative change from baseline to treatment in each of the four categories was 0.13 improvement for "interest", 0.11 improvement for "perception", 0.16 improvement for "ability", and 1.8 improvement for "independence". Note that "independence" was measured on a scale of 0-100, while the others were all on a scale of 0-5. Nevertheless, these preliminary results suggest that a course with M&T and gaming elements leads to modest improvement in each of the four categories.

II. Focus group results

In this section we present selected data from a focus group conducted at the end of the treatment offering. Near the completion of the course, an hour was set aside for a voluntary focus group session run by an education researcher, who asked students several questions in the absence of the instructor. Due to space limitations, we only present results for the most relevant question: "What aspects of the course were most helpful in developing new skills?" Students discussed possible responses in small groups, then amalgamated a list of the responses from the entire class. The students then individually scored each response from 1 to 5, with a 5 indicating the student fully agreed with that response. The mean and standard deviation of these scores for the highest-averaging responses are listed in Table II.

TABLE II

FOCUS GROUP TOP RESPONSES DURING TREATMENT OFFERING OF EE 361 TO QUESTION "WHAT ASPECTS OF THE COURSE WERE MOST HELPFUL IN DEVELOPING NEW SKILLS?" 19/24 STUDENTS PARTICIPATED.

Course Aspect of Feature	mean	std. dev.
Instructor's enthusiasm / knowledge	4.95	0.23
Intuitive explanations	4.84	0.38
Open-ended labs, especially antenna	4.74	0.65
In-class examples & exercises	4.58	0.61
Using labs as practicums for getting familiar with tools / skills	4.50	0.62
Flipped lectures / optional videos	4.37	0.68
Using videos to go in-depth on derivations introduced in class	4.26	0.81
Homework sets focused on skills	4.11	0.74

While the top two responses appear to focus on the quality of instruction, the third highest rated response – and the one most relevant to the present work – is that students strongly valued the open-ended labs/activities, and they found the antenna lab to be particularly useful in developing new skills. Again, as multiple gaming and M&T interventions were added to the treatment offering, it is not possible to isolate and quantify the impact of the two specific activities considered in this paper; yet, the qualitative results of the focus group suggest that the antenna activity is indeed highly valuable.

Finally, we emphasize that the preliminary evaluation results presented in this section are from two offerings of a single course at Western Washington University. As these results comprise a small portion of a three-year study spanning five courses across two universities [19], future work will include more data and detailed statistical analyses of the impacts of gamification and M&T, including the results of content assessments.

CONCLUSION

This paper presented two sequential activities designed for learning about RF path loss and antenna design in a junior-level electrical engineering course. The activities employed elements of making and gaming, both of which have been shown to be promising active learning approaches when used independently. The two activities presented in this paper, however, combined these two approaches. The first activity prompted students to conduct a free-space path loss experiment while attempting to find a hidden transmitter, while the second activity challenged students to design an antenna that could collect the most household gas meter readings over a five-minute interval. Preliminary evaluation data suggest that these two pedagogical approaches, when combined, are effective at modestly improving student interest, perception, ability, and independence. Future work will present a more detailed statistical analysis of the impact of gamification and M&T based on survey and content assessment data collected across five different courses at two universities as part of a three-year longitudinal study.

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