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Math Escape Rooms: A Novel Approach for Engaging Learners in Math Circles

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Engaging middle and high school students in Math Circles requires time, planning and creativity. Finding novel approaches to maintain the interest of a variety of learners can be challenging. This paper outlines a model for developing and implementing math escape rooms as a unique structure for facilitating collaborative problem-solving in a Math Circle. Undergraduate secondary mathematics education majors design and host these escape rooms. We provide possible structures for hosting escape rooms that could translate to a range of settings, as well as reflections and lessons learned through our experiences that could inform practitioners in other settings.

Keywords: Escape Rooms, Collaborative Problem-Solving, Middle Level Mathematics, Secondary Mathematics, Student Math Circles

1 Introduction

Escape rooms or escape games are quickly becoming an extremely popular pastime in recent years. Scott Nicholson loosely defines escape rooms as, ...live action team-based games where players discover clues, solve puzzles, and accomplish tasks in one or more rooms in order to accomplish a specific goal (usually escaping from the room) in a limited amount of time [1]. These activities are spreading across the globe, captivating the attention of both adults and children. In this article, we explore how secondary mathematics education students at a Midwestern university develop escape rooms for use

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in educational Math Circles. We examine the background literature regarding collaborative learning in STEM, discuss how escape rooms are being implemented by other professionals, explain our design and implementation of an educational escape room as a form of Student Math Circle, and reflect on our experiences and challenges in implementing escape rooms with students.

1.1 Collaborative Learning in Mathematics and Student Math Circles

There are many benefits of collaboration in STEM fields and in particular mathematics. PreK-12 mathematics education experts agree that the goal of mathematics teaching and learning is for students to develop a sense of procedural fluency that stems from conceptual models and processes, and that teachers need to situate this in the context of presenting high leverage math tasks that engage students in productive struggle [2, 3, 4]. Rather than teaching mathematics in traditional, non-participatory lecture-recitation methods, teachers are now encouraged to promote reasoning and collaboration in the classrooms [5,6]. Teachers promote inquiry-based learning strategies across STEM subjects in PreK-16 classrooms, which also require learners to engage in productive struggle, discourse, and experimentation with their peers.

Student Math Circles (SMC) represent a potential avenue for educators to maximize engagement and provide opportunities for productive struggle and collaboration in a gamified context [7]. In Student Math Circles, students collaborate with peers from mixed grade levels and engage with low floor high ceiling math tasks [8]. Unlike traditional mathematics practice that often focuses on rote memorization of decontextualized material, in SMC students engage with application level tasks collaboratively, which allows them to develop social learning, [9] whereby they can help one another learn and construct mathematical meaning together [10]. According to Bolognese Shahani, Student math circles genuinely allow students to take on the role of a mathematician. Through collaboration, curiosity, communication, and conjecturing, students of all ages can find real joy and success in doing mathematics [7]. Thus, Student Math Circles provide opportunities for diverse learners to engage in contextualized, discourse-based mathematics that is at the same time challenging and rewarding for students.

1.2 Benefits of Using Escape Rooms and Collaborative Technology

Studies show that incorporating more game-based learning opportunities for students is not only engaging, it also promotes critical thinking [9]. Those who lead SMC are, as a result, constantly looking for new and innovative approaches to engage students in gamified mathematics learning. A potentially under-researched avenue for facilitating SMC is in the form of the mathematics escape room. Escape rooms, first popularized in Japan [1], provide a thematic structure in which participants work in teams to discover clues and solve puzzles in order to escape from the room within a given time limit. Research indicates that the collaborative nature of escape rooms can develop communication, teamwork, and leadership skills among participants [11], and that participants develop better active listening and conflict resolution skills as a result of engaging with their peers to complete the room successfully [12].

In educational settings, escape rooms allow participants to apply learning from the traditional classroom setting in novel and contextualized ways. An educational escape room/game is defined as an instructional method requiring learners to participate in collaborative playful activities explicitly designed for domain knowledge acquisition or skill development so that they accomplish a specific goal (e.g., escape from a physical room or break into a box) by solving puzzles linked to unambiguous learning objectives in a limited amount of time [13]. In a study of escape room implementation in higher education, results showed that this fostered collaborative problem-solving and teamwork among students, which participants reported as a highly motivating form of practice and assessment [14]. Additionally, participants reported that the integration of mixed reality technology increased motivation and enjoyment while engaging in the escape room task. This could lead to an increase in students interest in STEM by affording them positive experiential learning opportunities in non-traditional settings. However, little to no literature exists at this time on the actual implementation of escape rooms in PreK-12 settings, thus this article seeks to add to the literature on the development of educational escape rooms for younger audiences.

1.3 Challenges of Implementing Escape Rooms and Collaborative Technology

Although utilizing escape rooms in educational settings is promising in terms of increasing student motivation, collaborative problem-solving skills, and teamwork/leadership skills, putting together and implementing these activities successfully does not come without potential challenges. Escape rooms and similar interactive learning experiences take time, planning, funding, and sufficient personnel to support [15]. In addition to these issues, depending on the number of student participants, logistical issues such as how many rooms and how much space are needed to accommodate larger numbers of participants, and the need for additional materials to support multiple spaces replicating the same room, become additional factors that educators may face.

There is little empirical research that reports the range of issues that may arise when enacting escape rooms in educational settings [7]. As a result, educational entities that develop and deploy these activities rely heavily on the broader research indicating an increase in participant motivation, collaboration, and critical thinking as adequate rationale for integrating game-based learning approaches into their programs. In this article, we share our own experiences developing, planning, and implementing educational escape rooms with a mathematics focus in a university-supported program where undergraduate STEM majors create SMC outreach opportunities for local middle school students. We examine both the structures our program has put in place to successfully develop and implement math escape rooms, as well as share lessons learned for other organizations and educators interested in developing their own escape rooms as Student Math Circles.

2 Design of the Escape Room

Our Student Math Circle development is situated within a larger National Science Foundation grant, part of the Robert Noyce Teacher Scholarship Program, in which we enroll undergraduate students with interests in STEM fields and STEM education in paid internships and scholarship opportunities. As part of the outreach component of our NoyceMATH program, our Noyce Interns and Scholars engage in a range of mathematics, teaching, and learning activities, with outreach to our local PreK-12 STEM educational network being a major lever for participation. Over the past several years, NoyceMATH Interns and Scholars piloted several iterations of mathematics escape rooms, both for our summer Eureka STEM camp, sponsored through Girls Incorporated, and as extracurricular STEM programming for local middle school students during the school year. In this section, we detail the steps our undergraduate student Interns and Scholars developed over time to create and implement math escape rooms as an outreach event, as a means of engaging students in doing mathematics and promoting critical problem-solving skills. In the following sections, we share our experiences about the planning, logistics, and successful implementation of these events in a university setting, with the hope of helping other educators and organizations effectively develop their own SMC.

2.1 Developing Escape Room Facilitators

Our first student escape room originated with a former scholar who attended a NCTM conference and learned about a teacher who used the concept of an escape room as a review activity. The following summer, a group of Scholars created our first escape room for a local middle school STEM camp. The reactions from students during the first escape room were overwhelmingly positive and we made the decision to use this model as a means of engaging students in Math Circles. Following this initial success, our Scholar team from the first summer mentored new Scholars and Interns as they developed additional Math Circles for the next years summer STEM camp, utilizing the concept of the escape room to excite and engage middle school students in mathematics.

Since then, our group has shifted from hosting these events solely at summer camps, and instead we now host student Math Circles several times a year on our university campus. Scholars and Interns work collectively in a variety of roles, including a lead role, which is an individual responsible for the overall operation of the escape room (typically a Scholar). Additionally, the leader works closely with newer Scholars, preparing them to assume the leadership role in the future. There are also roles for Scholars and Interns who are not in lead roles, including providing oversight of the rooms on the day of the event and assisting the room leaders.

These roles lead to a natural progression, beginning as an Intern assistant and eventually taking on leadership roles in hosting an event. For most Interns, this is their first experience with the creation and implementation process of a mathematics escape room, so they have fewer responsibilities and we pair them with a seasoned Scholar to help answer questions along the way. Scholars are usually room leaders who see to it that student participants collaborate and stay on track, providing hints as needed and preventing frustration from devolving into destructive struggle. Ideally, Scholars participate in the creation of several rooms before stepping into a leadership role. The creation and implementation of these escape rooms is a process that we constantly refine and improve upon, especially as new Interns and Scholars join our Noyce program and these new voices provide new perspectives.

2.2 Developing the Cold War Escape Room: An Illustrative Example

For one of our initial escape rooms, we used a Cold War theme, which merged mathematics with history. The initial planning process began with a large group of Noyce students meeting in a classroom on campus. We formed smaller sub-groups, identified relevant mathematics that would be appropriate for middle school students (and utilized state mathematics standards as a guide), and each group created their own puzzles with little input and communication from other groups. This lack of communication and planning set up difficulties once the larger group reconvened. We forced the puzzles to fit together in an unnatural way, which produced unforeseen challenges, including a lack of flow between the mathematics used as students progressed through the room. We recognized the importance of having a clear goal and process from the start, and our initial escape room proved that the organization and design of the room matters [13].

Although the Cold War escape room was largely successful in engaging middle school students in mathematical problem solving, we ran into several challenges. As the event took place, we became aware of an unanticipated issue. We found that the difficulty level of some of the puzzles was too easy while other puzzles were too hard. Additionally, the puzzles did not get progressively harder, as we originally intended. Some students became discouraged as they struggled to finish even one puzzle. Frequently, the students struggled with the puzzles in terms of knowing the appropriate mathematics to utilize. Students were often uncomfortable with the productive struggle aspect of problem-solving, and the fact that the escape room required them to work collaboratively [4, 6]. Unfortunately, students encountered one of the most difficult puzzles in this escape room first. We overlooked the issue since we did not test the puzzles and the room until the day of the event, and fellow college students conducted the trial. Due to this oversight, we did not notice the difficulty disparity for middle school students nor the lack of difficulty progression throughout the game.

During the event, our facilitators engaged with students, providing prompting questions and suggestions as needed when students exhausted their initial attempts at solving puzzles. Our intent in doing so was to maintain a high level of cognitive demand for each puzzle to keep students struggling in a productive manner [4, 7]. After this early attempt at organizing and facilitating a mathematics escape room for middle school students, we reflected on the pitfalls we experienced during the development and implementation of our early mathematics escape rooms. In the following section, we provide specific suggestions to plan successful mathematics escape rooms for students.

2.3 Applying Lessons Learned to Future Iterations: The Harry Potter Escape Room

After the Cold War event, we identified several problematic issues and developed strategies to improve our planning process for the next escape room. When we endeavored to create another new escape room, a Harry Potter themed one, we again began the planning process by meeting in a classroom on campus. Rather than starting with the creation of individual puzzles, we worked together to create a web (see Figure 1) for the escape room, which served as an overall map for the room. The web provided clear directions as to which puzzles connected to one another and in which order, along with details about each puzzle [13]. See Appendix A for a complete outline of the planning process and the puzzles for the Harry Potter Escape Room.

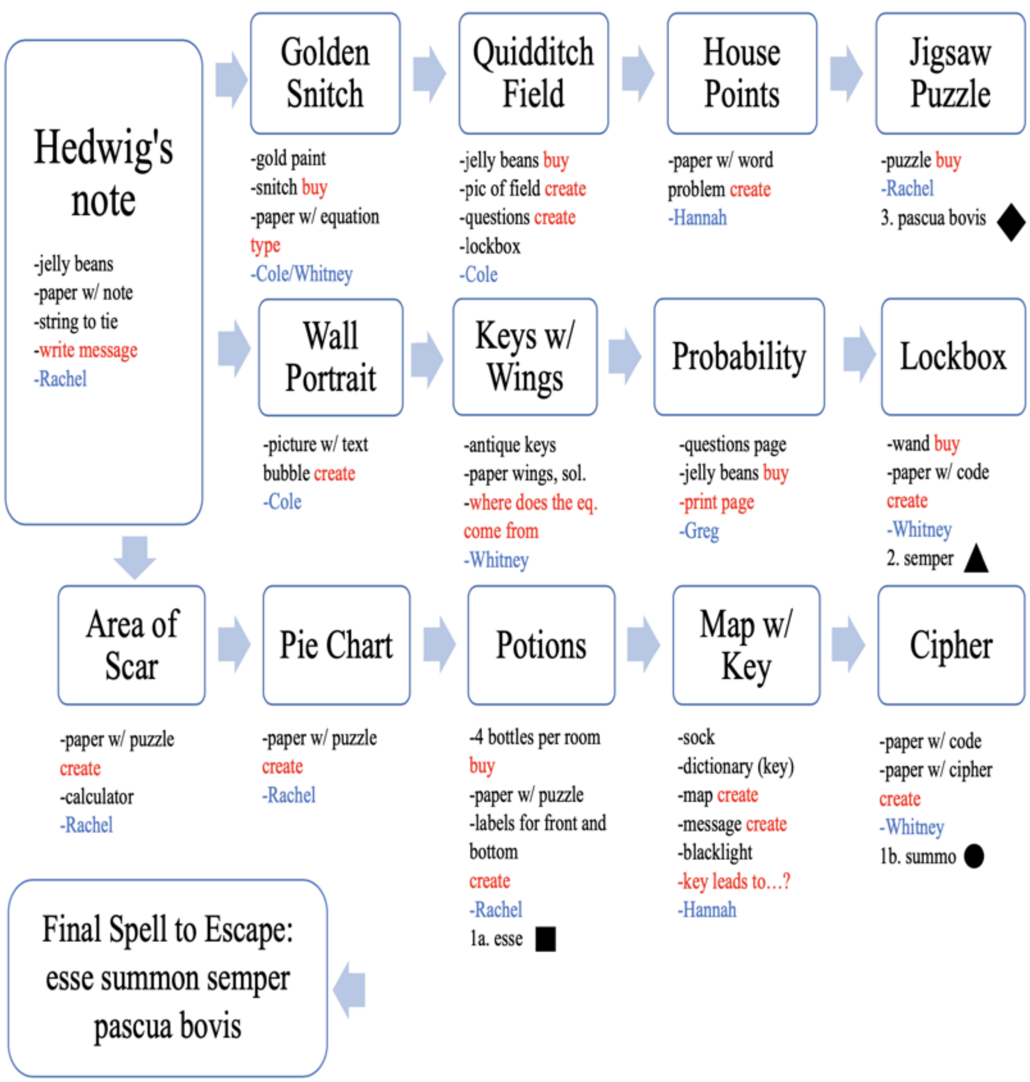

Figure 1. Harry Potter Escape Room Planning Web.

After we completed the web, we assigned a state mathematics standard that targeted participants grade level to each section of the web. Aligning the content to standards assisted us in determining an appropriate zone of proximal development at which to design puzzles that engaged students in productive struggle and required collaboration to solve [11, 16, 17]. After we identified mathematical concepts to target for the puzzles, we subdivided the group into pairs and assigned each pair to a section of the web. We charged each team with making a puzzle that fit the mathematical concepts aligned with each section of the room (See Appendix B for the listing of puzzles, along with the associated mathematics standards).

We began creating math escape rooms with the intention that students would experience math in a new and engaging way. We recognized that to attain this goal we first had to create problems that facilitated collaboration and a higher level of thinking. We began by looking at middle school mathematics standards [12] to ensure that we created puzzles based on topics the students had a foundational knowledge of and that led to critical thinking without causing destructive struggle [11, 2]. As we created puzzles, each group of Scholars and Interns chose different standards and worked to design puzzles based on those respective standards.

We present here three examples of linked math puzzles for one section of the Harry Potter web in Figure 1. These puzzles illustrate the threaded nature of the escape room design that allowed students to progress through the puzzles productively, as one puzzle led to the next.

> **Puzzle One: Marauders Map** (CCSS.M 6.G.A.1, finding the area of a triangle) Students will find the map lying on a table, some of the information on the map is written in invisible ink and will need to be decoded. On back is the Find the Area of Harrys Scar puzzle. Two right triangles are pictured with the perimeter given in cm for each. Students must determine the base (a) and height (b) for each triangle so that the area of the larger triangle is 4 times that of the smaller triangle.
>
>> *We thought it would be funny if you found sides a, b, a', and b' of Harry's scar for us. Write your results using the references we've included. P.S. You'll want to consult the half-blood prince for further instructions... and make sure to check out page three hundred and ninety-four ;-)*
>
> Puzzle gives the perimeter of both triangles ($P1 = 12$cm; $P2 = 24$cm) and includes graph paper for students.

Solution: Triangle 1 $a = 3$cm, $b = 4$cm, $c = 5$cm (Area = 6 square cm); Triangle 2 $a' = 6$cm, $b' = 8$cm, $c' = 10$cm (Area = 24 square cm) Thus: $3, 4, 6, 8$ is the final solution.

Puzzle Two: Mystery Graph (CCSSM.5.MD.B.2, represent and interpret data; CCSSM.6.RP.A.1 understanding concepts of ratios) After finding the a and b sides of both triangles, students enter the values into a circle graph that is hidden in a book on page 394.

> *The percent of cats and ratio of owls to rats will reveal your next clue. Professor Snape may think your results are interesting...*

% cats = ____________

Ratio of owls to rats = ____________

Students will need to find the cat and rat slivers of the circle graph: the sections of the graph are color coded:

Toad - 8
Owl - 12
Cat - 160
Rat 16

Solution: Cats = 80%. Ratio of Owls to Rats = $\frac{3}{4}$

Puzzle Three: Mixed Up Potions (CCSSM.6.NS.A.1 Apply understanding of multiplication and division to fractions and rational numbers) Using the rats and cats calculations, students must go to the potion bottles in the room where a number of potion bottles are sitting. Each of the bottles is labeled to show how much of a full bottle remains: 20% Skele-Gro, 60% Polyjuice, 80% Felix Felicis, 100% Confusing Concoction. Hidden underneath the 80% bottle is the following puzzle:

> *Heres a neat trick to increase your luck, drink $\frac{3}{4}$ of whats left of this Felix Felicis potion. If you can determine how much of the total bottle you downed, a clue within a nearby source can be found.*

Solution: 60% of the total bottle. Students will find the incantation word part ***ESSE*** (final puzzle) inside the Polyjuice bottle.

The overlay of the puzzle organization from the onset of planning allowed the small groups to collaborate and determine how the puzzles could coalesce in a natural way. If a group finished early, they worked together to make a stand-alone bonus puzzle that gave the students advantages in the escape room, such as extra time or clues for other puzzles. Once the pairs developed puzzles for their portion of the escape room, the larger group reconvened. Within the larger group, each pair presented their puzzle, methods for solving, connections to the rest of the web, and what materials were needed to create it. During this stage we also added the puzzles to a collaborative online document with each puzzles explanation and solution (see Appendix A). We made a second document that contained pages for the individual rooms. Each page consisted of a puzzle title and a solution to be kept in each room as a key for the room facilitators during the event. In addition to these documents, we redesigned the ways in which we provided structured supports during the event itself. We also addressed the need for collaboration among participants and the anticipated amount of struggle students would likely encounter with each puzzle.

To do this, we more clearly defined the role of our facilitators to assist students as they engaged with various puzzles in the room. We wanted students to collaborate on meaningful mathematics and to experience productive struggle but recognized this required an inquiry-based approach that provided direction and encouragement. To assist student struggle, we made several specific changes to our facilitation role. First, we built in structures to support struggle by providing a set amount of time for students to work collaboratively before we stepped in to help. After our early experiences, we recognized that intervening and guiding too early resulted in students finishing puzzles quickly, and more importantly, eliminated the opportunity for productive struggle that results in enhanced problem solving. We realized that since we saw the solutions from the beginning, it was easy to push them too quickly in the right direction rather than allowing students to discover the path themselves. We created several hints to provide when students struggled for too long on a particular puzzle and developed a range of questions to press their thinking and maintain the cognitive demand of the tasks [16]. These questions included prompts such as: What are you trying to find out? What do you know so far? What extra information might be helpful? What have you tried to connect these two things?

Finally, after creating the web and the puzzles, and after designing supports and structures to run the individual rooms, we gathered all needed materials and planned an escape room trial run. We invited a group of friends not involved in the planning process to participate in the escape room. This trial run provided us valuable insights into the room design, and we identified any missing items, along with puzzles and directions that needed clarification. Watching the events unfold during the trial run became a crucial part of the planning process that allowed us to better anticipate challenges as they played out in real time. We also identified alternative problem-solving strategies and incorporated them into our planning documents. We found it imperative to schedule the trial run with adequate time to address concerns and make changes before the day of the actual event. The feedback provided by our peers became a critical part of the planning process. From our initial attempts at designing an escape room with disconnected puzzles and mathematical concepts, we improved our planning process through iterative revisions. Whereas Figure 1 provides a contextualized example of the web design from our Harry Potter escape room, Figure 2 illustrates a more generalized web from which an escape room could be designed.

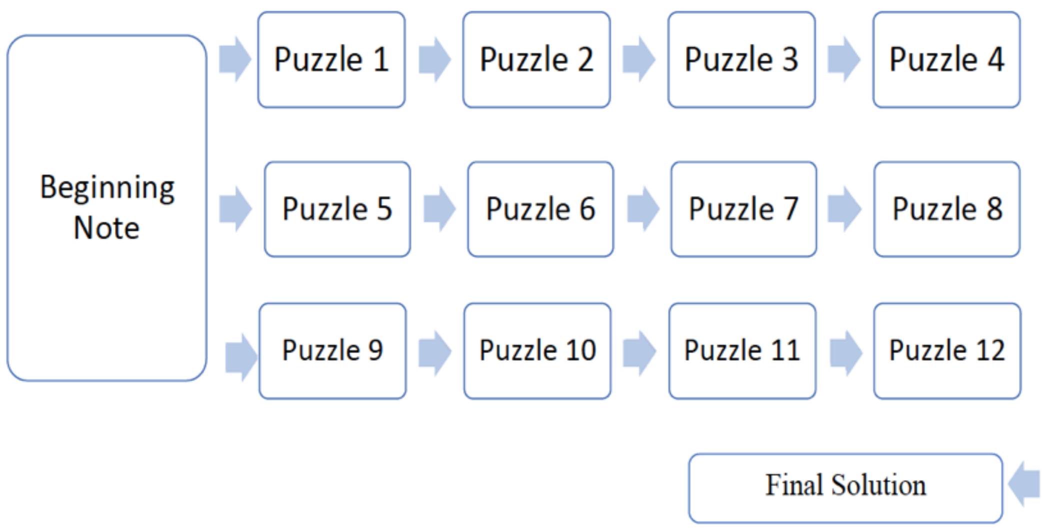

Figure 2. Generalized Escape Room Planning Web.

Our hope is that the use of this improved planning process results in an improved product in future iterations. The escape rooms can run more efficiently and ultimately, be a better experience for students.

3 Implementation of Mathematics Escape Rooms

Implementing a well-planned escape room involves more than simply designing mathematical tasks and puzzles. First, after planning out all of the puzzles, we need to order supplies. At our institution we are fortunate to have funds available for purchases such as these built into the budget of our scholarship program, but these costs are of consideration when designing a themed escape room. For our Harry Potter escape room, some of the items purchased were specific to the Harry Potter theme, but other more general materials, such as ribbon, duct tape, and lock boxes, can be reused in future escape rooms.

We also realize that advertising plays an important part of creating an escape room. We create flyers and email them to middle school math teachers and ask them to share the event information with parents and students. Parents then register students for the event and provide information about their child. With the information parents provide, we proactively address concerns such as food allergies and health problems that could arise during the students time with us. After working out the details and getting students signed up, we then stage the actual event. Many of the Noyce Scholars and Interns reserve the entire day of the escape room to dedicate to the successful set up and implementation of the event. We run three iterations of the same room during the event, so we prepare in advance materials for each of the rooms. For our Harry Potter escape room, we tried to make the rooms look like authentic Hogwarts classrooms, with rows of long desks and potion bottles scattered along the walls, to pique students interest in the puzzles embedded throughout the room. We assign staff to help facilitate in each room, to take pictures in all rooms, and one person to act as a floater between rooms to keep everyone moving at a similar pace. We prepare staff facilitators ahead of time with questions, prompts, and hints to engage students in the specific mathematical tasks and offer encouragement and direction without diminishing the cognitive demand of the tasks whenever possible.

After all of the preparation, we then host the event! When students arrive, they check in with their parents/guardians. We designate the first half hour to eat pizza, allowing our staff time to mingle with students. The middle school students get to meet the college student facilitators, as well as other middle schoolers from around the area. Although not part of the formal escape room, we realize that this pre-event time is critical to building a level of trust and rapport, both among students and between students and our facilitators. When students make these connections ahead of participating in the formal escape room, they are more likely to engage in collaborative problem solving with their peers, more likely to work with the facilitators to share ideas and frustrations, as well as to ask questions [11, 12]. We run three rooms to enable us to host more students while still keeping the room size small enough to engage all the students in the mathematics rather than just a few participants doing most of the work. We use different techniques to group students each time, such as sorting students by shoe size, to ensure random assignment to the three rooms. We provide the students with a few instructions, then send them to the rooms! We enjoy watching the students work together to solve the puzzles and engaging with them.

As we design subsequent escape rooms, we constantly reflect on our previous experiences to determine ways to refine and improve. A major goal during implementation is for students to work collaboratively and support one another in problem solving. To do this more effectively, we plan the escape room with three branches, where the first puzzle breaks into three sections to work on. The intentional non-linear design inherent in our escape room results in puzzles that are more likely to be solved through the coordinated efforts of participants. Although we often create a separate bonus puzzle not needed to solve the room as an alternative for students who would like to work alone, our goal is to encourage and facilitate conversation and the sharing of strategies and ideas among participants.

Throughout the event, we pay attention to the flow and pace of the room, as well as to the mood and progress (or lack thereof) of the students. Momentum in the rooms often comes and goes in waves. There are periods during which everyone is stuck, but when one group successfully solves a puzzle, the students get excited and this re-energizes the room. When students see their teammates untangle a puzzle, they want to see how the puzzle was solved and ask their peers to jump in and help with another challenging puzzle. As this happens, we often see groups rotate through the various puzzles to take turns and share the work of completing all puzzles before time runs out. When students get frustrated, we find it is important to focus on the progress they have already made. It can be challenging to hold back from telling students the answer at times, particularly when the group is nearly there, but we recognize the need to maintain the cognitive demand where possible [16]. Instead, we walk them back through what they've done so far to help them make mathematical connections and hopefully solve the riddle on their own.

Traditional escape rooms adhere to a time limit within which participants need to escape. Although we recognize that thinking deeply about mathematics takes time and we want to model and support this with our students, we also realize that an event such as this needs a clear starting and stopping point. With this in mind, we plan the rooms as much as possible to anticipate students ability to finish within the allotted time. In most of our experiences, students finish within about 10 minutes of the time limit, and we often allow students to work beyond the time limit to finish so everyone gets that sense of accomplishment. If a group has a long way to go and limited time to finish, our hints and encouragement might become more frequent to ensure all students experience success. We try not to focus on competition between rooms. Instead, it is all about the experience and celebrating the challenging math students successfully accomplish in the time provided. We find that the experiences for students are overwhelmingly positive as a result of our efforts to address these factors in the planning and implementation of the room.

4 Reflection and Lessons Learned

We learned a variety of lessons from our attempts at developing and leading multiple mathematics escape rooms. We recognize that the funding and structure of our NoyceMATH program affords us unique support to enact this sort of SMC. Additionally, as we reflect on the iterative process of planning and enacting escape rooms, we share our advice in the following section for those interested in developing a mathematics escape room as an SMC in their own educational setting.

4.1 Reflections on Designing Escape Rooms

Designing these escape rooms presented a range of obstacles that we overcame and improved upon as we learned from our experiences. The challenges that we faced encompassed everything from small obstacles to big picture concerns. Through reflection and fine-tuning we established a process that works well for us to create these engaging problem-solving events. Additionally, each semester we include the next generation of Noyce Scholars and Interns in the design process to build on our historical knowledge, providing our group with a sustainable process to continue creating and hosting future student Math Circles.

In this paper, we shared many of the challenges we encountered with the initial design process of mathematics escape rooms as student Math Circles. Perhaps one of our most important takeaways is the need to routinely address the variety of mathematical tasks within the puzzles and across the room, including the identification of tasks that are of appropriate difficulty levels, to draw on participants background knowledge. We must also ensure that we incorporate high cognitive demand tasks that are accessible for all [4, 16, 18]. It is important for the planning team to discuss the level of struggle that is productive and what types of probing questions and hints can best nudge the students in the right direction while still engaging them in discussion and collaborative problem solving.

Another important component of the planning process is the utilization of the problem web during the initial planning phase. This physical reminder keeps the planning team focused on the overall escape room structure, without being detoured by problems or tasks that interrupt the flow of the room. This tool allows the planning team to examine the flow of the puzzles and the mathematics to ensure that the progression is logical and natural for participants. Communication between all those involved in the planning process is critical and the use of shared electronic files provides easy access for continual updates and refinements. Finally, it is necessary to host a practice run of the escape room, with attention paid to timing, level of problem difficulty, and design of appropriate interventions by staff to ensure the event is ready for live participants.

4.2 Reflections on Implementation of Escape Rooms

As we implemented the actual mathematics escape room events, we encountered different challenges, but learned from each of them. The challenges ranged from little wonderings to larger obstacles that required time and engagement of the planners to problem solve. We experienced many successes that made the process well worth the time and effort, and we celebrated everything from the small wins to the large triumphs.

In addition to planning for the mathematics and theme of the event, we learned that there are logistical considerations as well. To ensure students attend the event, proactive advertisement, both in the form of flyers and online recruiting, is necessary, as is creating a sign-up mechanism. Hosting a pre-event social time allows student participants to meet one another and the event facilitators for the evening, which can foster trust and rapport during the actual event. Planning for this portion of the event may require the purchase of materials not related to the specific escape room, such as snacks and supplies, as well as name tags so participants can get to know everyone in the room. We developed an easily accessible shared document that acted as our to do list for the month prior, week prior, and day of, to track these logistical considerations. We made available an online repository for all those involved in the planning process.

Once students enter the room, we find that it is important for the room facilitators to take an active role in facilitating collaboration and problem solving during the event. At times, students become discouraged or stuck, and the support of our facilitators helps them continue persevering through the mathematics needed to unlock each puzzle [16]. Room facilitators constantly take the pulse of the room to determine the types and frequency of support students need to experience both the challenge and success of tackling mathematics outside the classroom. Team runners ensure communication continues among the three rooms, providing a system of checks and balances that keeps all students moving productively through the rooms. Assigning specific roles to team members ahead of the event allows for successful implementation in the moment, resulting in an engaging and enjoyable experience for all involved.

These reflections and lessons learned illustrate that organizing and hosting an educational escape room requires much work. We find the greatest reward for the time and collaboration we put into hosting these events is the successes that we celebrate with students. Some of our most notable successes to date include increasing the number of participants to full capacity, as well as seeing repeat attendance of students who greatly enjoy the experience. At the end of the event, the smiling faces of the participants provide affirmation that they indeed appreciate our efforts. Additionally, we receive overwhelmingly positive feedback from the community at large in the days following an event, as word of the event spreads.

4.3 Future Directions

Escape Rooms are somewhat of a cultural phenomenon in todays world. Escape rooms can be a valuable tool to hook students interest and engage them in doing meaningful mathematics. We hope that community organizations, K-12 schools, universities, and other volunteer groups can learn from our experiences to bring educational escape rooms into their own settings. Although it takes time and organization to plan a successful escape room event [15], the reward of engaging students in collaboratiove and innovative mathematical problem-solving activities can generate enthusiasm and a joy in doing mathematics for a younger generation of learners. Given the popularity of the escape room, our team continues to develop new rooms around different themes to appeal to a variety of student groups (including newly developed virtual events). We continue to work with schools and community groups to provide a creative mathematical outlet for youth and promote a learning bridge between and among a variety of stakeholders as we broaden our net of engagement.

The themed escape room presents a unique opportunity to connect problem solving, cooperative learning in mathematics, and current cultural trends as an engaging avenue for a Student Math Circle. In this article, we outlined the development process of themed mathematics escape rooms and highlighted the attention to detail required to successfully run the event. We learned much from the mistakes and pitfalls we encountered in our initial planning and implementation process of building mathematics escape rooms. As a result, we hope that others will benefit from our experiences to create and produce efficient, enjoyable, and educational mathematics escape rooms in their own settings.

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Appendix A: Noyce Harry Potter Escape Room Shared Planning Document

Expectations and Initial Directions:

1. Students will be split up into three small groups of 7-10 per group.
2. No phones allowed, paper and pencils will be provided for math problems.
3. When entering the room, do not move the furniture around or try to open up the computer station, there are no clues hidden inside the furniture.
4. You must begin with the opening puzzle before moving to other parts of the room (opening letter).
5. There are three tokens easily visible throughout the room that you can collect. You may redeem them for a hint about any of the puzzles in the room. Once your three tokens are spent, you may NOT receive any additional help on any remaining puzzles.
6. If you find any lock boxes or envelopes you are not allowed to open them until you write in the correct passcode and check with a room facilitator.
7. The students will have one hour to escape the classroom. If students ask for hints to solve any of the puzzles there will be a time penalty of either 3 or 5 minutes added to their final escape time (depending on first/second clue given about a puzzle).
8. Students are expected to work together with all of their group members:
    i. Respect one another and each others ideas
    ii. If a student or group of students is working on a puzzle, do not take it from them or take control, work together instead
    iii. Not all students have to start at the same puzzle, students can split up and work in smaller groups

Debriefing Questions:

1. What did you find most challenging about the Escape Room?
2. What aspects of the activity did you enjoy the most?

3. How were you able to solve the puzzles when you got stuck?
4. What skills did your group need to be successful in escaping the classroom?
5. Which puzzle was most challenging and why?
6. If you could do the Escape Room again what would you do differently?

Escape Room Walk Through:

ESCAPE ROOM GOAL: Fred and George have locked you in this room, you have to get to your quidditch match before it begins. Find the snitch and the words to the spell that will unlock the door!

OPENING PUZZLE:

> *Greetings fellow wizards! By now you've probably realized that the door is locked and your wands are missing. We were far too bored with our signature pranks and felt like we could experiment a little...So welcome guinea pigs to our magical room of puzzles! We've concocted a number of interesting tasks to keep you busy! If you happen to get lost or don't know where to start, maybe try your hand at navigating with Moony, Wormtail, Padfoot, and Prongs. You won't be able to contact your professors from here, but we've left you their likenesses to keep you some company. A little birdy also told us you've got a Quidditch match against your biggest rivals today! So make sure to finish up quick to make it to the big game! Remember, Harry needs your help finding the snitch. We've also enchanted the door to open with the correct Latin incantation. You've got to find a wand and the correct words to open the door. After you've mastered our brilliant puzzles, wave your wand and utter the correct words and you should be free to go! Best of luck!*

FIRST STRAND:

Puzzle One: Marauders Map (CCSS.M 6.G.A.1, finding the area of a triangle) Students will find the map lying on a table, some of the information on the map is written in invisible ink and will need to be decoded. On back is the Find the Area of Harrys Scar puzzle. Two right triangles are pictured with the perimeter given in cm for each. Students must determine the base (a) and height (b) for each triangle so that the area of the larger triangle is 4 times that of the smaller triangle.

> *We thought it would be funny if you found sides a, b, a', and b' of Harry's scar for us. Write your results using the references we've included. P.S. You'll want to consult the half-blood prince for further instructions... and make sure to check out page three hundred and ninety-four ;-)*

Puzzle gives the perimeter of both triangles ($P1 = 12$cm; $P2 = 24$cm) and includes graph paper for students.

Solution: Triangle 1 $a = 3$cm, $b = 4$cm, $c = 5$cm (Area = 6 square cm); Triangle 2 $a' = 6$cm, $b' = 8$cm, $c' = 10$cm (Area = 24 square cm) Thus: $3, 4, 6, 8$ is the final solution.

Puzzle Two: Mystery Graph (CCSSM.5.MD.B.2, represent and interpret data; CCSSM.6.RP.A.1 understanding concepts of ratios) After finding the a and b sides of both triangles, students enter the values into a circle graph that is hidden in a book on page 394.

> *The percent of cats and ratio of owls to rats will reveal your next clue. Professor Snape may think your results are interesting...*

% cats = ____________

Ratio of owls to rats = ____________

Students will need to find the cat and rat slivers of the circle graph: the sections of the graph are color coded:

Toad - 8
Owl - 12
Cat - 160
Rat 16

Solution: Cats = 80%. Ratio of Owls to Rats = $\frac{3}{4}$

Puzzle Three: Mixed Up Potions (CCSSM.6.NS.A.1 Apply understanding of multiplication and division to fractions and rational numbers) Using the rats and cats calculations, students must go to the potion bottles in the room where a number of potion bottles are sitting. Each of the bottles is labeled to show how much of a full bottle remains: 20% Skele-Gro, 60% Polyjuice, 80% Felix Felicis, 100% Confusing Concoction. Hidden underneath the 80% bottle is the following puzzle:

> *Heres a neat trick to increase your luck, drink $\frac{3}{4}$ of whats left of this Felix Felicis potion. If you can determine how much of the total bottle you downed, a clue within a nearby source can be found.*

Solution: 60% of the total bottle. Students will find the incantation word part ***ESSE*** (final puzzle) inside the Polyjuice bottle.

Puzzle Four: A Hidden Message This puzzle starts with a winged key located on the bottom of one of the extra potion bottles.

a) Students will find a lockable dictionary hidden in Dobbys sock and use the key.

b) Inside there is a sock with a map/coordinate grid inside as well as a black light.

c) Located elsewhere in the room is a coordinate grid with the location of a third key drawn in with invisible ink. At the bottom of the coordinate grid is a clue that reads, You might need to shed some light on the situation to find what you are looking for. Students must use the black light to solve the puzzle/see the missing coordinate location of the next winged key.

d) The key will be taped to the bottom of a table (in the middle of the room) and leads to the Quidditch puzzle (Strand 3) and a cipher puzzle.

Puzzle 5: Cypher This! Students use the cipher with a list of given numbers to decode another incantation word part ***SUMMO*** (final puzzle).

G	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**
13	14	15	16	17	18	19	20	21	22
Q	**R**	**S**	**T**	**U**	**V**	**W**	**X**	**Y**	**Z**
23	24	25	0	1	2	3	4	5	6

SECOND STRAND:

Puzzle One: The Key Is... There are a number of flying keys hung around the room. The back of the Keys with Wings poster strategically placed in the room has the following word problem written at the bottom of it:

> *Several members of the Gryffindor Quidditch team were preparing for a Quidditch match. Each of them spent four hours preparing alone and then the group worked eleven more hours together. They were SO hungry, when they returned to the dorm, they ordered 16 Chocolate Frogs each but when they arrived, Harry took 37 of them before giving the rest to the team. As the Quidditch team divvied up the remaining treats, they realized a mysterious thing had happened- the number of hours they spent preparing for their match was the same number as the number of Chocolate Frogs they had ordered!! How many members of the Gryffindor Quidditch team were preparing for the match and then eating Chocolate Frogs?*

Solution: Students must determine the equation for each problem, then set the two equations equal to each other ($4x + 11 = 16x - 37$) together to determine that $x = 4$, so they look for the key with $x = 4$ written on the wing. This key opens a box with 2 bags of jellybeans inside.

Puzzle Two: Bertie Botts Every Flavor Beans After collecting the two bags of jellybeans, students need to find a third bag of jellybeans that is hidden in a lock box **(STRAND 3)**. The composition of each bag is as follows:

BAG 1		**BAG 2**	
Colors	**Flavors**	**Colors**	**Flavors**
Red = 3	Cherry = 2	Red = 7	Green Apple = 3
Green = 4	Dirt = 2	Green = 2	Earwax = 1
Yellow = 3	Strawberry = 3	Yellow = 5	Cotton Candy = 1
	Vomit = 1		Worm = 7
	Watermelon = 2		Rotten Eggs = 2
Total = 10		Total = 14	

BAG 3	
Colors	**Flavors**
Red = 2	Banana = 2
Green = 3	Soap = 2
Yellow = 3	Lemon = 2
	Booger = 1
	Tangerine = 1
Total = 8	

Using the bags of jellybeans, students must calculate the probability of three questions.

- *What is the probability you will eat a primary color bean?*
  Answer: $\frac{23}{32}$
- *What is the probability you eat a bad flavor?*
  Answer: $\frac{1}{2}$
- *What is the probability that you eat a primary colored bean that tastes bad?*
  Answer: $\frac{23}{64}$

The final combination locks code is composed of the digits in the fraction with the least value from your answers to the above questions (Numerator and then denominator).

Solution: 2364 unlocks a lockbox with a wand to cast the final incantation/puzzle and a code **SEMPER**.

THIRD STRAND:

Puzzle One: Snitch! Students must find the snitch in the room. Inside is a paper with the following problem:

$\frac{3}{5}$ *of the students at Hogwarts went to Diagon Alley for a shopping excursion. 84 of the students from House Slytherin were banned from going on the trip. How many students went shopping?*

Solution: 126 students; 126 will be the combination to a lock box.

Once students use 126 to open a combination locked box, inside the box will be the **first** bag of beans for the probability puzzle in **STRAND 2** of this puzzle.

Puzzle Two: Fast as the Speed of Light The second winged key (from the Coordinate Grid puzzle in **STRAND 2**) leads to a locked tackle box that is hidden in another location in the room

Harry Potter is flying on his broomstick and he reaches the other side of the Quidditch field in 15 seconds. The distance of the field is the combination you just discovered. Hermione went twice as fast as Harry across the Quidditch field. How long did it take her to cover the same distance? Hint: $s = \frac{d}{t}$.

Next to the puzzle is an image of the Quidditch field as a visual and the hint, *Consult Dumbledore about your answer*" to lead students to the posters of Hogwarts faculty members on the walls.

Puzzle Three: A Pictures Worth 1,000 Words Behind McGonagalls portrait will be this word problem:

> *Malfoy broke the enchanted hourglasses containing each of the houses points! We no longer have the total number of points. This is all we remember: Gryffindor has 2 times as many points as Hufflepuff, Slytherin has 25 more points than Gryffindor, Ravenclaw has 37 fewer points than Slytherin, Hufflepuff has the same number of points as Harrys speed flying across the Quidditch field.*

Solution:

$$H = 260$$

$$2H = G \to G = 520$$

$$S = G + 25 \to S = 545$$

$$R = S - 37 \to R = 508$$

$$\text{Total } = 260 + 520 + 545 + 508 = 1833$$

The solution box will be enclosed by a red box, a corresponding combination lock elsewhere in the room that uses this code. The code will also have a red box around it. Inside the combo-locked box will be a puzzle containing a piece of the final incantation: **PASCUA BOVIS**.

Appendix B: Harry Potter Puzzle Construction and Common Core Mathematics Standards Alignment

Puzzle	**Items Needed**	**CCSS-M Standard**	**Answer/What puzzle leads to**
Marauders Map	Invisible Ink to decode map with scar triangles on reverse side	6.G.A.1	A/B sides of 2 different triangles, these values are entered into the Mystery Graph
Mystery Graph	Book with circle graph hidden on page 394	5.MD.B.2 6.RP.A.1	Rat and Cat percent and ratio on the graph, which are used in the Potions puzzle
Mixed Up Potions	Potions (beakers filled with color dyed liquid), some with rational numbers adhered, key hidden on one of the extra bottles	6.NS.A.1	Part of final puzzle/incantation, Key to begin A Hidden Message puzzle
A Hidden Message	Sock, lockable dictionary, coordinate grid, black light	5.G.A.2	Key, which unlocks cypher puzzle
The Key Is...	Keys with wings - wings have answers to puzzle on lock, lock with equations	8.EE.C.8.C	Key will unlock a lockbox containing 2 bags of jellybeans.
Bertie Botts Every Flavor Beans	3 bags of jellybeans (2 collected from The Key Is, 1 collected from Snitch!), probability questions	7.SP.C.7	Solution will unlock a lockbox in the room
Snitch!	Plastic fillable ornament with wings adhered	6.NS.A.1	Solution will unlock a lockbox in the room that contains a bag of jellybeans
Faster Than the Speed of Light	Locked tackle box, Quidditch Field image and speed puzzle	6.RP.A.3.B HS.N-VM.A.3	Solution will help them begin the puzzle A Pictures Worth 1,000 Words
A Pictures Worth 1,000 Words	Posters of Hogwarts faculty, word problem posted behind image of Prf. McGonagall	7.EE.B.3	The total number of points = 4-digit number and that will unlock a combination lock to the final part of the incantation to unlock the room