A Simulation Escape Room: Verification and Validation is the Key

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Abstract

In this paper, an entrepreneurial mindset-based learning activity is designed to actively convey the concepts of model verification and validation (V&V). In particular, we develop an "Escape Room" entrepreneurial mindset learning (EML) activity where students are given a scenario and a set of "problematic" simulation models. Students work in teams to verify/fix and validate the models in order to "escape" (achieve a goal) before time runs out. This project addresses two critical aspects of modeling related to engineering design and analysis, namely, verification and validation. The escape room activity and outcomes are assessed using rubrics and student surveys. Results indicate that the activity is effective at engaging students in the application of model verification and validation which can be carried on to other engineering projects as well as fostering EML objectives of curiosity, connections, and creating value.

1. Introduction

Bosman and Fernhaber [1] describe an entrepreneurial mindset (EM) as "the inclination to discover, evaluate, and exploit opportunities" – a quality often found among highly successful engineers. Furthermore, an EM is a quality that can be enhanced and developed through experience and education [1]. In this paper, we explore the using an escape room concept as an educational activity to foster the development of an EM in engineers.

An *escape room* typically consist of a set of puzzles, clues, etc. that are solved by a team and lead to the goal of escaping from a room within a specified amount of time (see [2] for additional information and examples of entertainment-based escape rooms.) Recently, escape rooms have gained interest as a pedagogical tool in education [3, 4] in areas such as medical education [5], mathematics [6], and software engineering [7], among others. Although a fondness for entertainment-based escape rooms is the motivation, rather than solving puzzles and searching for clues in a physical room, teams apply simulation modeling techniques to work their way through a virtual room toward a final goal. In particular, we introduce an entrepreneurial mindset learning (EML) activity to actively convey the concepts of model verification and validation (V&V). In this escape room activity, students are given a scenario and a set of "problematic" simulation models. Students then work in teams to verify/fix and validate the models in order to "escape" (achieve a goal) before time runs out.

This activity addresses two critical aspects of modeling related to engineering design and analysis, namely, verification and validation. Verification is the process of determining that the model is free of modeling errors (i.e., debugging) and functions as intended. Validation is the process of determining that the model is an accurate representation of the system under consideration. A model is considered valid if decisions about the real system can reliably be made based on the results of the model. V&V is particularly important in simulation modeling as an analysist must demonstrate to a decision-maker that the models, on which recommendations are based, are accurate. Although these technical concepts could be taught to students in a multitude of way, this activity is designed to foster the development of an entrepreneurial mindset in students by appealing to and encouraging their curiosity, making connections, and creating value.

The remainder of this paper is organized as follows. In section 2, we discuss entrepreneurial mindset learning as it relates to simulation and the expected outcomes. The EML activity design methodology is presented in section 3. In section 4, we discuss an example implementation of the activity. In section 5, we discuss the results and outcomes of the escape room implementation. Finally, in section 6, we present our conclusions and insights for future course development.

2. Entrepreneurial Mindset Learning Activities in Simulation

Although often associated with individuals that take the initiative to develop a product or service into a company (i.e., entrepreneurs), an entrepreneurial mindset is a way of thinking that can be developed and applied by everyone. Bosman and Fernhaber [1] provide an in-depth discussion on how engineers, in particular, can benefit from developing an EM through engineering education. A leading proponent of developing EM in engineers is the Kern Entrepreneurial Engineering Network (KEEN). In particular, KEEN has created an EM framework that focuses on three primary EM characteristics: curiosity, connections, and creating value (the 3 C's) [8]. By questioning the status quo and exploring alternative points of view (curiosity); integrating information from multiple sources/experience (connections); and seeking opportunity for creating extraordinary value, an EM can enable an engineer to become a high-level contributor to the development of products and services that have significant societal benefits.

Efforts related to fostering an EM in engineers has been gaining momentum across all of the engineering disciplines. Here, we focus on EML approaches that have been applied systems simulation (a core course in many Industrial Engineering curricula.) A simulation applications activity [9, 11] encourages students to explore the vast array of simulation applications, identify an application of their own interest, and report the societal, economic, and/or environmental benefit of the simulation-based solution. An open-ended simulation activity [9, 11], encourages creative solutions to a transportation problem in a theme park environment where students consider both the performance of the transportation system but also the value the solution provides in terms of entertainment and sustainability. Finally, an EML project-based learning activity [10, 11], centers on the design of a full-scale production system based on a lab-based production system prototype. The project provides the opportunity to conduct a complete simulation study with the goal of considering both system performance and sustainability measures of alternative system configurations. Each of these EML activities develop the student's technical abilities while fostering their EM by promoting curiosity, connections, and creating value.

Likewise, the escape room activity is designed to enable students to learn about the concepts and importance of model verification and validation through an active learning module that will help foster an entrepreneurial mindset. The goal is, that following the activity, students will make V&V an integral part of their simulation modeling and analysis process that will be reflected in course projects and beyond the course itself.

The expected technical and entrepreneurial mindset related learning outcomes for the escape room activity include the following:

- Demonstrate understanding and effective use of model verification and validation techniques (Curiosity, Connections, Creating Value);
- Explore the accuracy and validity of a model from a contrarian point of view (stakeholder/decision-maker) vs. a modeler (Curiosity);
- Assess and manage the risk associated with the validity of the model. That is, what is the risk associated with level of model abstraction relative to recommendations/decisions (Connections);
- Persist and learn from failure through the process of verification and modeling issue resolution (Creating Value); and
- Demonstrate the contribution of V&V to model/recommendation credibility (Creating Value).

Although the escape room activity will focus on simulation related V&V methods and techniques. The approach and activity have the potential to be generalized to verification and validation methods in an array of models for engineering design and analysis.

3. EML Escape Room Activity Design

The design of an EML escape room activity involves several important considerations including designing the activity framework, developing an engaging scenario, crating the simulation models, identifying potential failure modes, creating a means of assessment, and designing an implementation plan.

The escape room activity framework is shown in Figure 1. In particular, teams of students are provided a scenario with their ultimate goal. Then, teams are provided with a series of simulation models related to the theme of the scenario each having a verification/validation challenge.

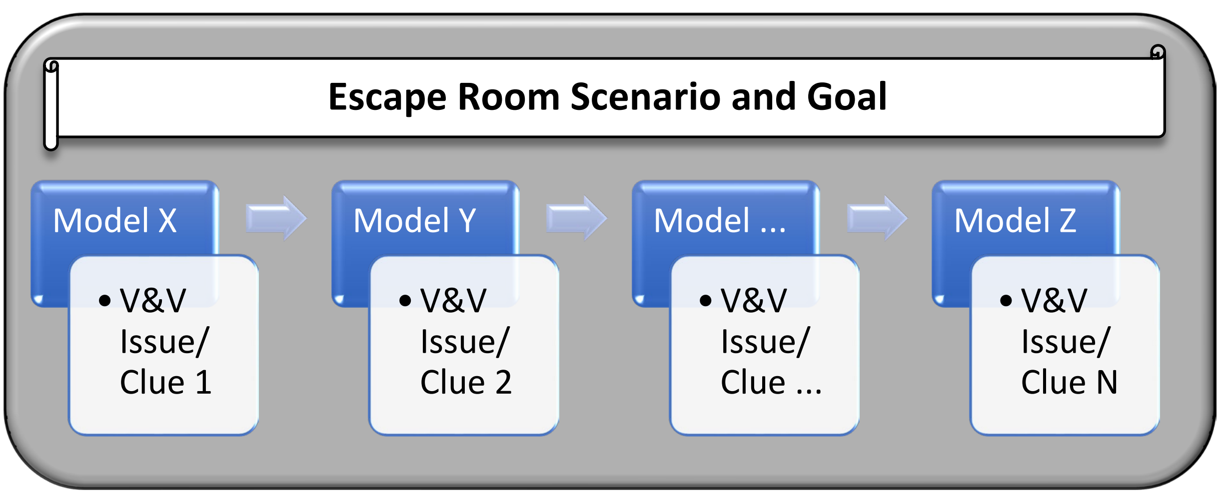

Figure 1: V&V Escape Room activity framework.

To start of the activity, students receive the first simulation model (Model X) which contains modeling errors/issues along with clues or observations about the V&V issues. The group then works to solve these issues and move on to the next stage (Model Y). The group receives clues or observations about V&V issues in the second model and proceeds to address the issues to obtain a verified/valid model. This pattern will continue until the students reach a verified and validated model for the scenario. The final stage includes running an experiment and obtaining information that will provide the "key" to escape.

Given this overall framework, the next step is to define plausible scenarios that will engage students in the activity and provide ample opportunity for applying V&V techniques. Examples could include a manufacturing, healthcare, warehousing, supply chain or other system. In our escape room example, a bike production system design was chosen for several reasons. First, a bike is something that almost everyone is familiar with and has had experience with at some point in their life (from an EM standpoint the establishes an immediate connection). Second, this familiarity with the structure/components of a bike, enables smooth implementation as minimal information is needed to convey the steps of the production process and class time does not need to be used to explain the application. Third, the conceptual bike production process was able to be broken down into component submodels with minimal dependance one another. Finally, a plausible goal (meeting a design deadline) was able to be established. Note that, although the simulation models for each stage can be independent, to keep with the escape room concept, a theme that relates them to a final goal is desired.

The next step is to create the simulation models. Our approach is to build the simulation model of the scenario for the final system representation. Then, working in reverse order, errors and inaccuracies are introduced along with the clue and information for that stage. The clues could be in the form of written information or perhaps a video that would emulate feedback from a stakeholder or decision-maker. Additional model stages are added until reaching the initial model and information that will be provided to the students. We found this to be the most challenging and time-consuming task.

To help ensure a smooth implementation of the activity, a thorough evaluation of the potential failure modes and remedies will be critical. For example, if a student team gets "stuck" on a particular stage, perhaps a set of hints could be made available with a time penalty that would enable the team to proceed to the next stage. As potential failure modes are identified, alternative remedies can be generated. If possible, we suggest recruiting a set of student volunteers (students that have previously taken the course are good candidates) to test and provide feedback on the scenarios and implementation process.

A grading rubric for the activity should be developed and provided to the students prior to the start of the activity. In our example, the graded deliverables include the submission of the verified/validated simulation models for each stage along with a worksheet where students indicate what they observed that indicates the model is not verified/valid; what action was taken to correct the model; and after making changes to the model, what they observe that indicates the model is

correct/valid. In addition, we suggest administering an activity survey to assess the technical and EM learning outcomes, as well as to solicit feedback on how the activity could be improved.
In the next section, we provide an example of an EML escape room activity that was implemented in a systems simulation course.

4. Example Escape Room Implementation

The example EML escape room activity is titled, *Simulation Escape Room: V&V is the Key,* with a subtitle *To Escape: Beat the Design Deadline*. We use our initial implementation of the escape room collect feedback about the effectiveness of the activity and to inform improvements. The simulation models for this activity could be implemented using any simulation software, in this case, we utilize Simio [12] simulation software as it is the software used in the course.

The escape room scenario focuses on a production systems design company called Tiger Systems Design (TSD) that is trying to meet a design deadline which includes a verified and validated simulation model. In particular, the scenario is as follows:

> *TSD is competing with other companies for a multi-million dollar contract to design and build a state-of-the-art bike production facility for the Innovative Bicycle Company (IBC). To win the contract, TSD must provide both the design concept and a dynamic simulation that demonstrates the capabilities of the design. TSD has a winning design; a simulation has been created; but… the SIMULATION IS NOT WORKING! Your team has been tasked with fixing, verifying, and validating the simulation model. However, THE DESIGN DEADLINE IS IN <u>ONE HOUR</u>!*

Instructions that we provide to the team prior to the start of the activity include the following:

- Each group must work independently. You may not share information between groups.
- Your team must verify and validate the models one at a time in the order provided.
- This file includes a section for each submodel that contains, the system description followed by information about the "issues" with the submodel.
- Your team must complete the V&V Activity Report and submit the report at the end of the activity.
- Your team must submit each corrected (verified and validated) model before proceeding to the next model.
- Each member of the team must submit an Activity Survey at the end of the activity.

An overview of the bike production system is shown in Figure 2. The activity is broken down into five submodels (orders, wheels/gears, frame, handlebars/brakes, and crank/pedals) and a final assembly model. Students verify and validate each of submodels in sequence and then the final assembly submodel. Since the component models are not independent of one another, the order submodel is verified, validated, and submitted first. Then, a valid (correct) order submodel is used to generate demand for each of the parallel subassembly models. After each of the subassembly models are submitted, the corrected models are used in the verification and validation of the final assembly model which encompasses the entire production system.

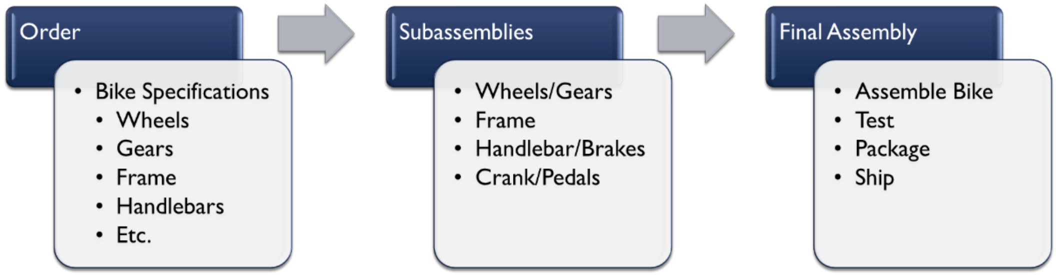

Figure 2. Bike production system workflow.

To illustrate the process of completing the activity, we present two of the submodel V&V challenges – bike orders and wheel/gears.

4.1 Order Submodel Challenge

For bike orders, bike model characteristics and demand information are provided. The demand model is a Markov process with an average arrival rate of four bikes per hour. In addition, there are 10 bike models consisting of a combination the following: two frame styles, two wheel sizes, three gear choices, two pedal types, and two brake types. Table 1 shows the bike model configurations and the demand mix.

Table 1. Bike model configurations and demand mix.

Bike Model	Demand Mix	Frame Style	Wheel Size	Gears	Pedal Type	Brake Type
1	5%	1	24	10	1	1
2	10%	1	24	18	2	2
3	5%	1	26	10	1	2
4	10%	1	26	18	2	2
5	15%	1	26	21	2	1
6	5%	2	24	10	1	1
7	5%	2	26	10	2	2
8	10%	2	26	18	2	2
9	15%	2	26	21	1	1
10	20%	2	26	21	2	2

A problematic "Order" simulation model is provided to model the arrival of bike orders for the demand mix of bike orders. This submodel is for the order arrival process only (the production processes are not included.) A table in the simulation model stores the bike configuration. Two state variable columns are set up to track the number of orders created for each model and the number of bikes entering the sink (released to the production floor.) Also, an experiment is set up to enable multiple replications with three primary performance measures. (Students are welcome to add other performance measures as needed.) The simulation is set up to run as a non-terminating system for 240 hours (representing thirty, 8-hour days where the ending state of one day is the starting state for the next day of operation.) In addition, a list of general issues is given.

For bike orders, an error is introduced for the demand mix, and the incorrect probability distribution is used for the order interarrival time. However, the information the students are given is that the issues include (1) the number of arrivals is different than expected, and (2) the resulting mix of bike orders is different than expected. Students then run the simulation model and utilize the verification and validation techniques discussed in class (observing animation, evaluating performance measures, conducting model trace, conducting structure walk-throughs, etc.) to identify and correct errors/inconsistencies in the model.

While conducting the verification and validation of each model, the students complete a V&V Report which involves addressing the following three questions:

1. Before making changes, what do you observe that indicates the model is not verified/valid?
2. What action was taken to correct the model?
3. After making changes, what do you observe that indicates the model is now correct/valid?

Finally, the students submit their verified and validated model to an assignment dropbox.

4.2 Wheel/Gear Submodel Challenge

A corrected Order model is used to supply the demand for the four parallel subassembly models. Here we discuss the Wheel/Gear subassembly model, but the other bike subassemblies follow the same approach. A flowchart with an accompanying note as shown if Figure 3 is provided along with the problematic submodel. In this case, an error is introduced for the allocation of the worker and there is an error in the process flow. The information the students are given is that the issues include: (1) the Wheel Kit Worker is not being utilized, and (2) the expected time in system for Wheel Kits should be approximately 0.71 hours.

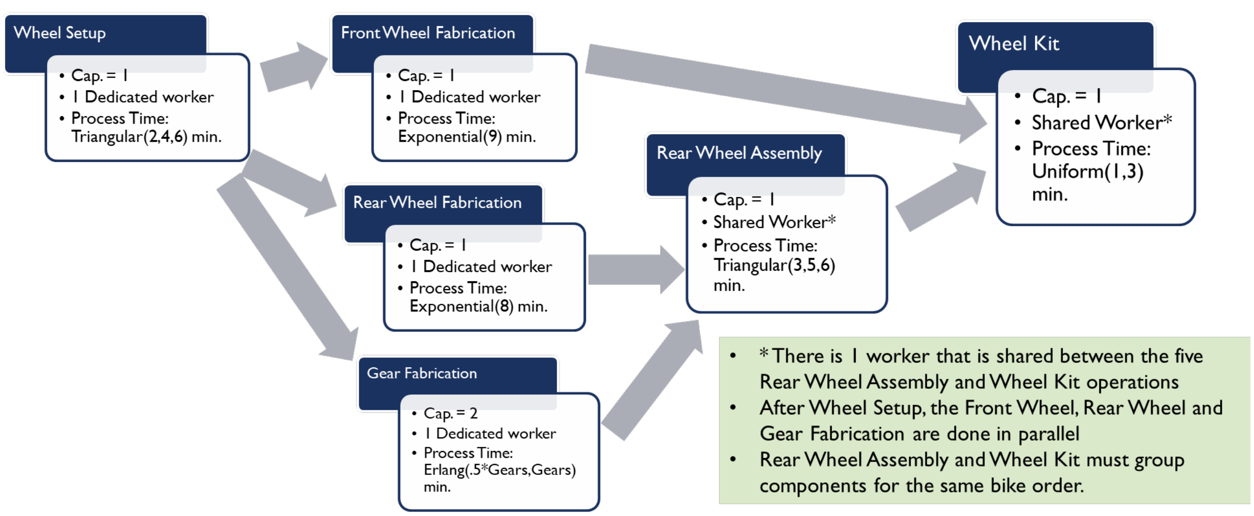

Figure 3. Wheel subassembly production workflow.

Again, students then run the simulation model and utilize the verification and validation techniques. to identify and correct errors/inconsistencies in the model. In doing so, they complete the V&V Report and submit their verified and validated model to an assignment dropbox.

4.3. Completing the Escape Room Activity

After completing the verification and validation of the order submodel and the four parallel subassembly submodels, the final V&V activity is to complete the verification and validation of the final bike assembly model. A flowchart and additional information (similar to Figure 2) are provided for the production flow and requirements for the final bike assembly, packaging, and shipping. The simulation model includes the corrected and order and subassembly submodels, and students only need to address the issues in the final assembly portion of the full production system model. Similarly, students are provided the expected performance metrics that can be used for validation. Students then run the simulation model and utilize the verification and validation techniques. to identify and correct errors/inconsistencies in the model. In doing so, they complete the V&V Report and submit their verified and validated model to an assignment dropbox. If students validate the final model within the one-hour deadline, the successfully *escape*.

To address the potential exercise failure mode of teams getting stuck, hint cards are given to each team. If a team wants to use a hint, they turn in one of the hint card and the instructor provides some useful advice that directs them to the source of the error in the model. Rather than a penalty for using a hint, teams are given a bonus point for each unused hint card at the end of the exercise. Also, to avoid the issue where a team finishes much earlier than expected and have nothing to do the remainder of the period, as part of the final deliverable, a professional-looking animation is requested. Finally, in the case where a group has technical difficulties or is unable to complete the activity in the one-hour time limit, students would be given the opportunity to complete the activity outside of class.

Additional details about this project-based EML activity including the activity narrative and rubrics are available from the KEEN Card 4049, Simulation Escape Room: V&V is the Key (see [13]. Note, accessing KEEN Cards on the website [8] is free, but requires registration.)

5. Outcomes and Assessment

We implemented the EML activity as a lab session during the fall semester of the 2023-2024 academic year. Eighteen students, in groups of size 3, participated in the activity. Each of the groups worked independently. The duration of the lab session was 75 minutes. The first 15 minutes was used to organize the students into groups and introduce the activity. Then, students had the remaining 60 minutes to complete the activity (a timer was projected on the screen in the lab so students could track their time remaining.) Our objective is to evaluate the extent to which students engaged in the three aspects of an entrepreneurial mindset – curiosity, connections, and creating value. To evaluate the level of engagement, we employ a rubric for grading the verified/validated models and the V&V Activity Report, and a reflection using a post-activity survey.

A grading rubric was provided to the students at the start of the activity. In this case, the rubric was fairly simple in terms of assessing how well the group was able to identify and correct errors in the model and the reasoning provided for why the corrected model was valid. Overall, the performance of the groups was excellent except for a couple of instances where the groups seemed to run short on time.

At post-activity survey specifically designed to assess the effectiveness of the EML activity was administered. The students were asked to complete the six-question survey by indicating the extent to which they agree or disagree with each statement. The survey utilizes a five-point Likert scale with the following responses (weights): Strongly Agree (5); Agree (4); Neutral (3); Disagree (2); and Strongly Disagree (1). The survey questions along with a summary of the responses is provided in Table 2. Each students completed the survey independently for a total of n=18 survey responses. The average and standard deviation of the Likert score is provided for each question. In addition, survey included two open-ended questions asking students to, (1) indicate the things you liked about the activity; and (2) provide any suggestions for improving the activity in future semesters.

Table 2: V&V activity survey questions and response summary.

Activity Survey Questions [5-Strongly Agree; 4-Agree; 3-Neutral; 2-Disagree; 1-Strongly Disagree]	**Response Average (Std. Dev.)**
Q1) The activity prompted asking question and discussing V&V.	4.11 (0.83)
Q2) The project prompted gathering/observing data/information to support ideas and solutions.	4.33 (0.49)
Q3) I took ownership of, and expressed interest in, the V&V activity.	4.44 (0.62)
Q4) I was able to connect my previous experiences with some aspect of the activity.	4.11 (0.47)
Q5) The activity prompted me to why/how verification and validation adds value to a simulation project from technological, economic, societal, or other perspectives.	4.39 (0.61)
Q6) The activity prompted verification & validation of a simulation model to meet customer needs.	4.50 (0.51)

The six survey questions were designed to align with desired EML outcomes. The responses for each question indicate that the activity provided opportunities for the students to apply EM related concepts and skills of curiosity (Q1 & Q2), connections (Q3 & Q4), and creating value (Q5 & Q6). Given that this is not a formal, controlled study and that the implementation engaged a relatively small number of participants, we cannot conclude this EML activity significantly impacts the entrepreneurial mindset of students. However, the empirical evidence demonstrates EM objectives of the activity are being met.

6. Conclusion

In conclusion, we presented an EML escape room activity for systems simulation courses that will compel students to actively apply verification and validation techniques rather than just hearing about V&V in a lecture and applying the techniques on an ad-hoc basis. This activity is also intended to enable a more thorough evaluation of V&V concepts as well as foster the EM characteristics of curiosity, connections, and creating value. The desire is that V&V techniques will be applied to projects and go beyond the classroom to demonstrate model accuracy and support recommendations to stakeholders and decision-makers. Future work includes the development of EML activities to improve the teaching and comprehension of other simulation topics.

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