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The Meme Game: A Hands-On Activity to Introduce First-Year Engineers to Concepts in Mathematical/Computational Modeling

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Introduction

Engaging with real-world systems requires that engineers model and quantitatively assess their behavior. While this practice is of key importance to modern engineering practice, engineering students rarely engage with the full modeling process—an indispensable tool when classic models reach their useful limits, and also a crucial component of the scientific process. Specifically, students are rarely asked to construct novel models for physical systems. Instead, they are typically asked to re-derive and mathematically analyze existing models. Consequently, students also rarely practice verification and validation of models.

This study presents a framework for introducing, motivating, and engaging first-year undergraduate engineering students in the modeling process through a participatory scenario of social “infectivity.” Our novel full-class activity, dubbed the “Meme Game,” features an exchange of doodles which results in the viral propagation of certain doodles across the player population. The activity makes explicit connections to epidemiology and sociology via design choices which offer direct analogies between the game and real-world scenarios of infectious disease spread and social mimetics/information spread. In the wake of the COVID-19 pandemic and with the proliferation of disinformation on social media, the domains associated with our activity have become especially relevant and motivating to students.

We used the Meme Game as a first-day activity for an introductory course on modeling and simulation at a small engineering-focused college. Our results suggest that the activity successfully provides immediate exposure to an interesting physical system, to which an array of accessible modeling approaches can be applied. Since the activity (and subsequent analysis) relies on relatively little background knowledge, first-year STEM students can effectively engage with the game, and some students can produce novel models of the game’s behavior. This challenges an assertion sometimes made in modeling pedagogy—that undergraduate students lack the domain knowledge necessary to engage fully in the modeling process [1]. Additionally, the proposed activity results in a rich student-generated data set which motivates a variety of questions about viral phenomena, and offers the opportunity for students to meaningfully answer these questions by validating their models against real-world measurements.

This paper describes the full logistics of the activity (including methods for collecting and synthesizing the generated data), describes outcomes from our runs of the Meme Game, and presents example modeling of the activity conducted by both the instructional staff and students. An approach to incorporate the activity into broader lessons on the importance and practice of scientific modeling is discussed, as are implications to undergraduate engineering education.

Related Work

Modeling is considered central to modern problem solving [2]–[4]. Much of modern engineering practice relies on the process of building and analyzing models of real-world phenomena. Modeling is a complex process that draws on a diverse set of practical and conceptual skills. Modeling has become an increasingly important skill due to the rise of computation, which now lies at the heart of quantitative analysis in science and engineering. As described by Coleman & Steele [5], recent advances in computing have the promise to reduce costly physical experimentation through computational modeling. Computational approaches have been thoroughly adopted in sectors such as aerospace design [6].

However, the teaching of modeling in undergraduate engineering is fraught. As noted by Downey [7], “Some students learn (modeling) skills implicitly, but in most schools they are not taught explicitly, and students get little practice”. Gainsburg [8] has characterized the teaching of modeling as “haphazard, unintentional, and under-theorized.” Key pieces of the modeling process are frequently not taught. In particular, we identify *abstraction* and *validation* as two key parts of modeling that are not often taught in engineering education.

Abstraction—the process of selecting which features of a physical system to include in a model and how to represent them—is key to developing models. Gainsburg [8] has synthesized steps of the modeling process from literature; in her language, what we call “abstraction” includes the first three of six steps to modeling:

1. Identify the real-world phenomenon
2. Simplify or idealize the phenomenon
3. Express the idealized phenomenon mathematically (i.e., “mathematize”)
4. Perform the mathematical manipulations (i.e., “solve” the model)
5. Interpret the mathematical solution in real-world terms
6. Test the interpretation against reality

In traditional engineering curricula, students rarely participate fully in these choices: abstraction decisions have usually already been made. Instead, students are tasked with steps 4 through 6, particularly on “solving” the model. For example, students may be explicitly instructed to neglect friction or air resistance in projectile motion in a course on physics. This problem structure gives students no chance to engage in abstraction. In her study of structural engineering faculty, Gainsburg [8] found that instructors believe that students lack the domain knowledge to meaningfully engage in steps 1 through 3. More broadly, scholars of modeling have found that undergraduates’ limited domain knowledge is a barrier to learning modeling [1].

However, using models to solve nuanced real-world problems requires engineers to critically consider their abstractions. As Gainsburg [9] documents, practicing engineers employ *engineering judgment* to regulate their mathematical activities, including modeling. Engineering judgment gives a "sense of what is important" and "separates the significant from the insignificant details," including selecting or rejecting the unprovable starting assumptions that are used for building and analyzing mathematical models—the abstraction choices in modeling.

Beyond abstraction, *validation* is another key part of modeling (a form of Part 6 above). Developing accurate simulations of physical systems and confirming their usefulness is a challenge. This need to confirm the fidelity of models used in safety-critical systems gave rise to the activity of verification and validation (V&V) [10], [11]. Practitioners of V&V aim to *verify* the correctness of model implementations and *validate* their model results by comparison with real-world behavior (e.g., [12]). Principled V&V enables confident endorsement of a model, for a specific use case. Despite its central importance to modern engineering practice—to our knowledge—V&V is rarely discussed at the undergraduate level.

Introducing the critical lens of verification & validation early in the curriculum is especially important due to potential pitfalls surrounding computational modeling. As Lingefjärd [13] documented, masters students building models in a computational environment would lend an unreasonable level of trust to the results of those models. In a sense, computing would 'take over' and students would not engage in critical thinking to critique their own models. Lingefjärd's studies "confirmed the essential role played by the validation part of mathematical modeling when technology is present." Explicit instruction and practice in validation may contribute to training students who exercise *engineering judgment* to wield and consume computational models critically.

While explicit teaching of modeling is rare in undergraduate education, there does exist prior work in this space. A very closely related effort is that of Rosenbaum and colleagues [14], who used handheld digital devices in a "participatory simulation" of the spread of a virus among university students. While their goals emphasized exploring then-novel technologies for use in the classroom, our approach is deliberately analogue. They hypothesized that direct involvement in a modeled simulation would help students better understand a particular model of the scenario—this is closely related to our own instructional goals, but our focus is on the modeling process, rather than improved understanding of a specific model.

Gainsburg [8] opined that the work of Lesh and colleagues "may be the most thoroughly developed modeling initiative in engineering education," and thus their line of inquiry is a useful comparison for the present work. Lesh and colleagues [15] developed the approach of model-eliciting activities (MEAs) originally for K-12 education, but these have been adapted to engineering education settings (e.g., [16]). MEA design has a strong focus on research methods; they were developed as a scalable alternative to clinical interviewing. Intrinsic motivation is not a strong focus of MEA design, while our institutional context strongly emphasizes intrinsic motivation—a value that our teaching team also shares [17].

Adaptations of the MEA approach to engineering education include the work of Diefes-Dux [16], Hjalmarson [18], and colleagues. Their MEA—the Aluminum Crystal Size MEA—had first-year students develop a procedure to quantify crystal size from technical images. This activity offers students an experience developing a reusable procedure that is representative of authentic engineering practice. This is an extremely valuable experience for engineering students. However, our work has distinct instructional goals—supporting abstraction and validation. We describe those goals and methods next.

Context, Goals, and Methods

Our proposed activity sits within the context of a first-year, first semester course on modeling at Olin College. During the run of the course studied in this work (Fall 2022), n=81 students participated in the class. The primary learning outcome of this course is to teach students the full modeling process (Steps 1—6 above), but with a particular focus on *abstraction* (Steps 1—3 above) and *validation* (Step 6). This focus on abstraction and validation is a recent feature of the course, the guiding decision of a curricular redesign over the summer of 2022. The full contents of this course are outside the scope of the present report; below, we describe the Day 1 activity we implemented to support this focus on abstraction and validation.

In our institutional context, Day 1 is expected to fulfill multiple important functions. Our institution emphasizes intrinsic motivation and hands-on instruction; therefore, there is an expectation that Day 1 will involve some form of activity (rather than a lecture or reading of the syllabus). Day 1 is also expected to "set a tone" for the remainder of the semester. Our activity is expected to connect to the primary learning outcomes of the course. These considerations served as boundary conditions for our design work.

Instructional goals

Given this, our instructional goals were to design an activity which is:

G1. *Simple* enough to enable any first-year college student to understand and participate in the activity, regardless of educational or social background; this is to promote equity in the course.
G2. *Rich* enough to generate interesting behavior that motivates a variety of approaches in quantitative modeling; combined with the lucidity afforded by G1, this goal is meant to make *abstraction* accessible to all students.
G3. *Instrumented,* in the sense that the activity generates a dataset that records state over time; this creates opportunities for model *validation*.

The intent of these goals were to design an activity that students would later model. In this way, we intended to overcome the “limited domain knowledge” barrier [8]. By designing an activity that students themselves had participated in, we aimed to equip them with the “domain knowledge” necessary to model the activity itself.

To satisfy these goals, we designed the *Meme Game*, an activity which mimics the viral propagation of ideas—*memes*—across a population as a result of interactions between individuals. Simple drawings/doodles represent the ideas being propagated; participants create and then replicate these doodles in a semi-structured fashion. Simple mechanisms are built into the activity through which participants collectively record the propagation of doodles across the population, enabling recording of the game’s state and subsequent validation exercises.

We chose to design in the space of viral meme propagation due to its relevance and accessibility. Parallels have long been drawn between the viral spread of ideas and diseases [19]–[21], thus enabling at least loose analogies between the sociological and epidemiological domains while avoiding the overt connotations of disease spread in the Day 1 activity. In the wake of the COVID-19 pandemic and with modern misinformation crises in social media, the importance of understanding and predicting viral phenomena is hard to understate. For those in the mathematical modeling community, COVID-19 served as a potent reminder of both the potential influence and realistic limits of the discipline [22].

Additionally, quantitative epidemiology is rarely covered in K12 curricula [23], can be treated with relatively simple mathematics (as demonstrated below), and has relatively little immediate conceptual overlap with more traditional introductory quantitative sciences such as mechanics and electromagnetism. These qualities put most incoming undergraduate engineering students on roughly equal footing for undertaking epidemiological modeling, promoting equity among our students.

Methods

To assess the degree to which the Meme Game satisfies our instructional goals (G1—G3), we applied a case study approach. The case study approach focuses on “in-depth study or examination of a distinct, single instance of a class of phenomena” [24]. This research tradition does not seek generalizability (in the positivist sense): We make no claims about the reproducible “effectiveness” of the Meme Game intervention. Instead, we seek to establish a contextualized understanding of the Meme Game—its design and our students’ experience of it.

While positivist approaches are sometimes treated as the only legitimate form of science, experts opine that purely quantitative, positivist approaches to inquiry are insufficient for scientific progress. For instance, randomized controlled trials (RCTs) are considered the “gold standard” of unbiased experimental design. However, experts assert that RCTs alone are not sufficient for scientific progress; that other methods are necessary "to discover not 'what works', but 'why things work'" [25]. Given the preliminary nature of the proposed activity, we aim to study "why" and "how" the meme game works, before attempting to establish the generalizability of the activity.

We describe the specific methods used in this study and their alignment with our instructional goals below:

- G1: *Simplicity* and *equity*. Admittedly, a case study approach is not appropriate for establishing that the proposed activities work for "all" students. Furthermore, the proposed activity is meant to serve course goals in multiple, distinct ways. Our observations from running the activity—namely, we observed engagement from all students—suggest that all our students could learn and participate in the Meme Game.
- G2: *Richness* and *abstraction*. Case study methods are well-aligned with assessing the *richness* of the proposed activity. As we will see below, there exist multiple, conceptually distinct ways to model the Meme Game. However, we do not assess the rate and degree to which students can perform this abstraction work on their own. We present student work that suggests some undergraduate students *can* do authentic abstraction work modeling the Meme Game.
- G3: *Instrumentation* and *validation*. The *instrumented* nature of the proposed activity is thoroughly established by our example modeling work. This constitutes an "existence proof" of the instrumentation and validation opportunities afforded by the Meme Game.

Description of the Meme Game

The Meme Game is the Day 1 activity for *Modeling and Simulation of the Physical World*, a first-year, first semester course on computational modeling at Olin College. The instructions below describe the step-by-step logistics through which the activity leaders guide participants. Each participant creates a doodle (of their own choosing), then partners with another participant to exchange doodles. While each individual exchange is quite simple, the accumulation of many such exchanges results in a dynamic evolution in the population of doodles over time.

The game was designed to be played with little prompting or initial context, beyond a presentation of the rules. Participants necessarily play a direct role in the emergent social phenomenon while simultaneously observing and recording a portion of the outcome. Even without priming, we have found that the global dynamics of the game naturally reveal themselves to participants through their limited firsthand observations. This is a powerful and intuition-priming experience that serves as grist for the abstraction work students will do throughout the rest of the course.

The game proceeds as follows:

1. In preparation, each student receives a pad of ~30 sticky notes, a writing utensil (such as a Sharpie), and a “datasheet” (Appendix A1) which is a sheet of paper with 3 designated areas for affixing a sticky note. We refer to each area as a “slot,” and together the 3 slots comprise a student’s “deck.”
2. Each student draws a doodle of their own design on a sticky note. A doodle should be as amusing as possible under a constraint of simplicity: any other participant should be able to re-draw this same doodle in approximately 15-20 seconds. This sticky note is affixed to their deck sheet, occupying the first of three slots.
3. (Round 1) Students choose a partner and each replicate their own doodle (that is, re-draw it on a new sticky note). Each student gives this replicated doodle to their partner, who adds it to the second slot of their deck. (Illustrated in Figure 1.)
4. (Round 2) Students partner with a new person. They again replicate a doodle on a new sticky, although now they may choose which of the 2 doodles in their deck to replicate. Again, each student gives this new sticky to their partner, who adds it to the final slot of their deck. Each student, having received 2 stickies, now has a “complete deck.”
5. (Round 3+) Students partner with a new person and replicate one of the 3 stickies in their deck to give to their partner. Upon receiving the sticky from their partner, this new sticky must be placed in one of the 3 slots in their deck. Thus they must choose which of their 3 currently-available stickies will be covered and thus made unavailable to duplicate; only the sticky at the top of each slot is ever considered available for replication.
6. Successive rounds continue like Round 3 until the game is concluded (at a round of the instructor’s choosing).

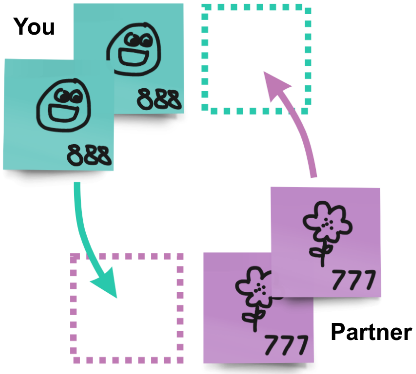

Figure 1 - Illustration of a doodle exchange in Round 1. Presented to explain the rules.

We instrumented the game as follows to track the prevalence of each doodle across time:

1. Each “datasheet” is marked with a unique identifier number (ID). Additionally, the sheets have numbered spaces for recording IDs as described in step 4.
2. When students create their initial doodle, they copy this ID into the corner of the sticky. Henceforth, this ID uniquely identifies that particular doodle and is considered an integral part of the doodle itself.

3. During each round, when replicating a doodle on a new sticky, students must include that doodle's ID alongside the doodle.
4. After each round, students record the 3 IDs of the doodles currently available in their deck in the corresponding data space on their "datasheet."
5. Once the activity has ended, students digitize their data. We created a simple spreadsheet template which lets students rapidly enter data and export it in a consistent format (Appendix A1). This enables parsing and visualization of the game's dynamic state.

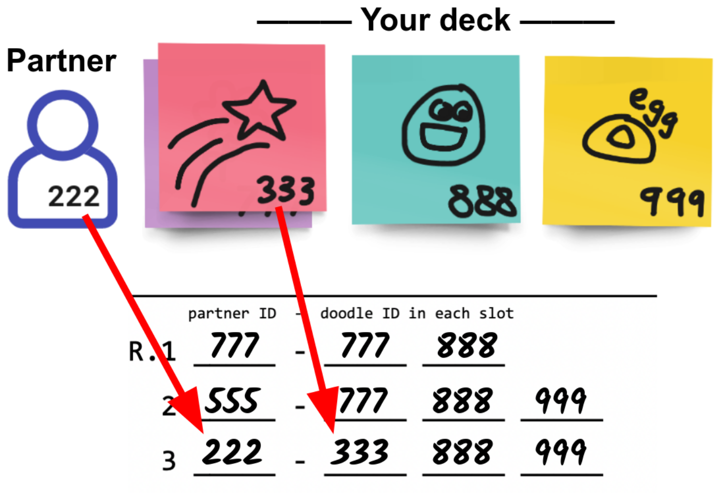

Figure 2 - Example of a participant's deck (above) and data sheet (below). Here, the participant has just completed round 3, where they replaced doodle #777 with the newly-acquired doodle #333.

Thus, the activity is designed such that each participant's limited deck—analogous to limited working memory—enforces a kind of natural selection of doodles, where those which are preferred tend to be replicated more frequently and covered up less frequently (Fig. 2). Thus, a higher preference at a local level results in increased prevalence at the population level.

Key to the activity's design is this way in which students' choices generate the data. Every doodle exchange requires an in-the-moment decision about which doodle to replicate and which to cover, thus directly influencing a doodle's prevalence. Ultimately, students observe how all these seemingly-inconsequential decisions accumulate into significant larger-scale trends across the participating population. This is intended to help students develop "domain knowledge" of the activity dynamics across scales.

Practically, the activity is best run in an open space which promotes continuous mixing of the participant population. Additionally, rounds should occur discretely and simultaneously across the population, such that every participant has engaged in the exact same number of doodle exchanges at all times. Centralized round announcements are useful here, although in practice we found it difficult to synchronize rounds perfectly, leading to some interesting aberrations in the data (discussed below). We found that, after a few longer introductory rounds, the round intervals required approximately 90 seconds to allow for the full process of partner matching, doodle duplication and exchange, and data recording. Based on observed engagement, we found the game is best run for ~25-30 rounds in total. In our trials, this duration prevented the activity from feeling needlessly repetitive while still producing interesting dynamics.

Results

We ran the Meme Game twice: first as a pilot with a year-mixed undergraduate population n=28, and later with a first-year class of n=81. Both trials successfully produced a rich set of data featuring a wide variety of cases of doodle virality. The trajectories of most doodles fell into one of three broad categories (Fig. 3):

1. Those which failed to spread through the population and quickly fell out of circulation.
2. Those which consistently gained prevalence over the course of the activity.
3. Those which gained in prevalence but then declined.

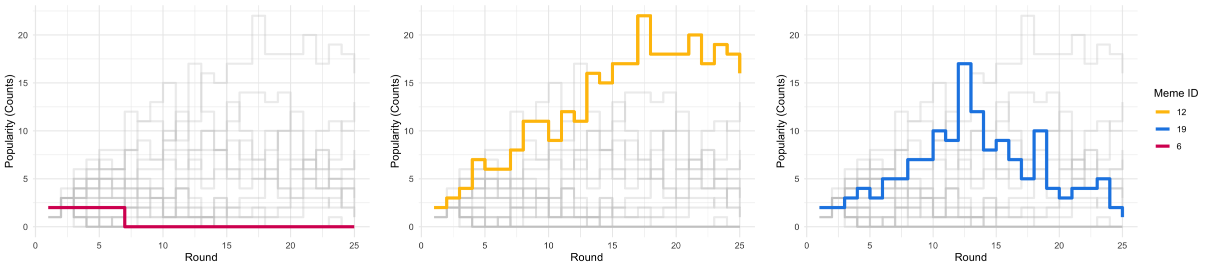

Figure 3 - Selected results of our pilot game, highlighting three doodles/memes with dramatically different trajectories in prevalence over time.

Such results are ultimately an emergent phenomenon relying on certain doodles resonating more strongly with the participating population than others: None are guaranteed to “go viral.” However, a trivial outcome is unlikely for several reasons. Variation in the initial set of doodles tends to be significant (Fig. 4); doodles which fall out of circulation cannot return from “extinction,” thus forcing the remaining doodles to increase in prevalence to fill all deck slots; and since the game generates one trajectory per meme (hence, per participant), interesting behavior is nearly guaranteed to be observed in at least some trajectories.

Figure 4 - Collections of the stickies generated during our runs of the meme game.

In both trials, participants followed instructions to varying degrees. This resulted in readily-identified errors in the aggregated data resulting from individual behaviors, such as non-synchronous rounds of doodle exchange, mistakes in data recording or digitization, or simply unreported data. For instance, the fact that some participants submitted more rounds' worth of data than others highlights the fact that rounds did not occur perfectly synchronously (Fig. 5). Additionally, while exactly two copies of every doodle should have been present in the population after the first round, this was not true of every doodle in our dataset.

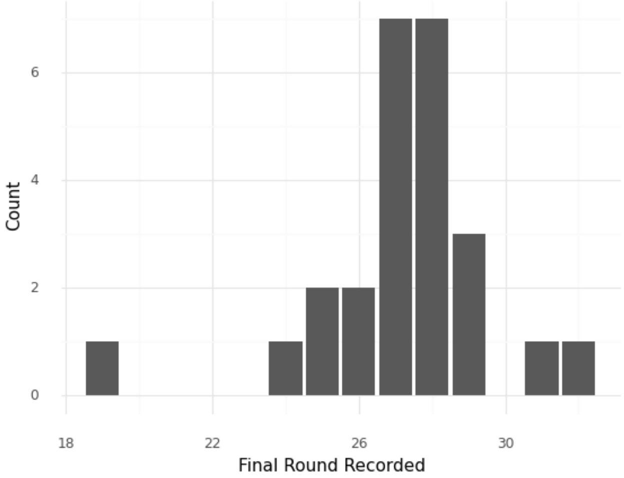

Figure 5 - Disparity in total number of rounds recorded by participants, demonstrating data errors from our pilot run of the Meme Game.

Such errors served as a useful way to illustrate the realities of data collection in real-world experiments. This highlights the richness and complexity of the meme game. Despite the activity being instrumented to allow a hypothetical perfect reconstruction of events, the data ultimately provide a noisy picture of reality.

Additionally, since successful doodles are redrawn many times by many different participants, noticeable drift in the character and details of particular doodles can be observed in the resulting collection of stickies. Such mutations of doodles across time directly mirrors those which affect viral ideas and diseases in large social systems.

Motivating modeling

In the Fall 2022 run of the course, we compiled the results from the game and presented them to students on Day 2. We used these results to motivate modeling by probing the limits of what questions can be answered with the data. The data does enable students to answer many questions about *what* happened. However, they are unable to meaningfully answer questions about *why* events transpired as they did or *what would happen* next, such as:

- How prevalent would a particular meme have become if the game lasted for another 15 rounds?
- What mechanism explains why many memes tend to rise and then fall in prevalence?

Students quickly realize that a quantitative representation of the system's evolution over time would enable them to answer such explanation and prediction questions by identifying some underlying mechanism and then extending the simulation timeframe. However, the behavior of the Meme Game clearly arises from an impossibly-complex network of human factors and decision-making. Thus, any attempt to model the Meme Game will necessarily omit detail, but may nonetheless prove useful for answering modeling questions.

In the Day 2 lesson, we provide students with physical materials (dice, beads, paper,pencils) and ask them to create some form of model for the meme game, based on answering a provided prompt. This activity is difficult by design: This task is intended to highlight the difficulties of abstraction before we introduce canonical modeling approaches later in the course. While the full details of the Day 2 activity are outside the scope of the present report, this Day 2 lesson sets the stage for our course's focus on abstraction.

Modeling the Game

Later in the course, we introduce canonical models for the spread of disease through a population. The earliest approach we introduce is a *compartmental* model; in particular, the susceptible-infected-recovered (SIR) model [26]. While we do not make the connection explicit to students, this model is one way to model the Meme Game.

The SIR family of models has its roots in modeling infectious diseases [27], but it has also seen use in modeling the spread of information in social systems [19]. This model divides a population into distinct "compartments" representing the number of individuals who are Susceptible, Infected, and Recovered from some infection. We use the Infected population to represent the total number of active copies of a chosen doodle across participants in the Meme Game. This roughly divides the participant population into those who have not been exposed to the meme and are thus *susceptible*, those who are *infected* with the meme and are actively propagating it, and those who no longer propagate the meme and are thus *recovered*. This aligns with a typical (though not universal) experience of a participant in the Meme Game; upon receiving a particularly amusing doodle, they might choose to exclusively replicate it for some number of rounds until getting bored and moving on.

Canonically, the SIR model is represented as a system of coupled ordinary differential equations [26], where the parameters β and γ represent the infection and recovery rates, respectively:

$$\frac{dS}{dt} = -\beta S(t)I(t)$$
$$\frac{dI}{dt} = \beta I(t)S(t) - \gamma I(t)$$
$$\frac{dR}{dt} = \gamma I(t)$$

However, when presenting to first-year students, we sidestep calculus by instead presenting the model as a system of difference equations:

$$\begin{aligned} S_{t+1} &= S_t - \beta S_t I_t \\ I_{t+1} &= I_t + \beta I_t S_t - \gamma I_t \\ R_{t+1} &= R_t + \gamma I_t \end{aligned}$$

Tuning the two parameters enables fitting to the distinct cases of meme dynamics identified in the game data. In this way, the infection rate β represents the initial attractiveness of a given doodle, while the recovery rate γ represents its longevity. Figure 6 shows the difference equation form of the SIR model fitted to two meme trajectories from the pilot run of the game.

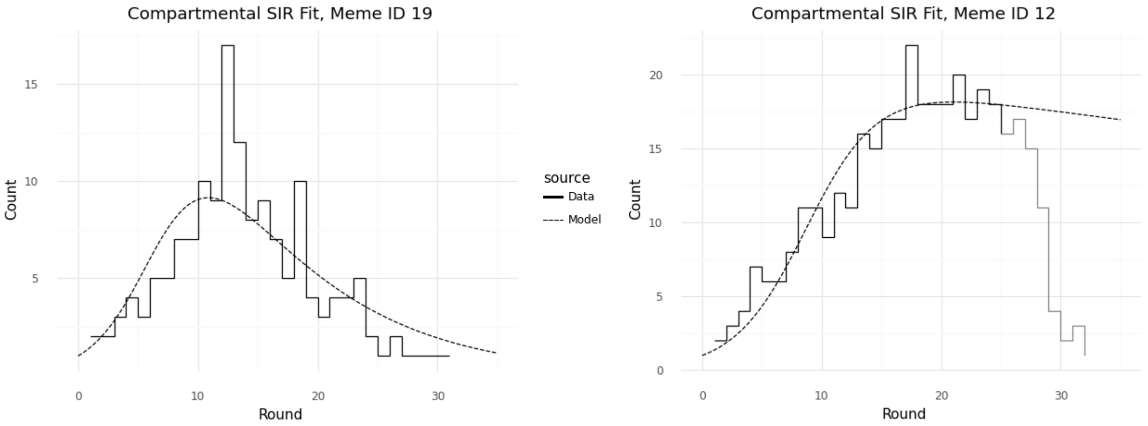

Figure 6 - Examples of compartmental SIR models fitted to experimental data from our pilot run. Note that in the second example, we assume that the model disagreement after Round 25 arises from aforementioned data errors; a minority of participants submitted data for later rounds.

The SIR model offers a rich lens for modeling the meme game. It is constructed to maintain a constant population [26], enabling introductions to conservation laws and offering a useful invariant for verifying simulation implementations. It has connections to sophisticated ideas in modeling: for instance, the SIR model invokes the law of mass action from chemistry [27]. Basic compartmental models are also readily extended with additional compartments and flows between them. Many such variations on the basic model have been studied, such as those with flows representing reinfection and SEIR models with incubation delays between exposure and infectivity [26]. Students in our course regularly explore these extensions in self-directed projects. This is our primary strategy to have students engage in self-directed abstraction choices—by making modifications to a base model in order to answer new modeling questions.

However, this compartmental model makes several key assumptions:

- Each doodle is treated as an independent viral phenomenon, and thus ignores the interactions between memes competing for popularity in the game;
- The model generates smooth and continuous trajectories which cannot reproduce the incidental fluctuations around the general trend observed in real meme game results;
- The model assumes perfectly homogeneous mixing of the participant population [27], thus ignoring the realities of social groups;
- The model includes no way to distinguish between particular members of the population, thus making it impossible to ask questions pertaining to any particular individual's interactions with the viral phenomenon.

Agent-based models offer an alternative approach to modeling the game, successfully bypassing many of these limitations at the cost of significantly increased complexity. The middle portion of the course focuses on modeling a disease infection as an evolving state on a weighted graph (representing social connectivity), which enables the explicit representation of social cliques and maintains a record of every individual's infection status over time. However, we focus our lessons on a critical comparison between compartmental and agent-based approaches, carefully considering which modeling questions would necessitate the additional overhead of the agent-based model. We pose this as an exercise in "justified complexity," based on a historical observation that students in our course tend to prefer adding complexity for its own sake, rather than adding complexity to solve specific modeling problems.

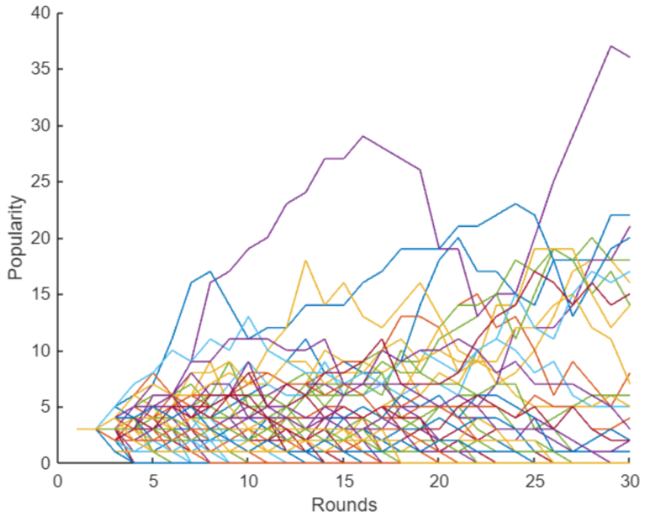

Figure 7 - Results of a student-designed model of the meme game. The model seeks to answer whether the diversity of meme prevalence trajectories observed in the experimental results can emerge from a model with no explicit differences in meme desirability. Student work by Daniel Heitz and Trinity Lee; used with permission.

We provide students with a working agent-based SIR model as a starting point in the mid-semester, which they modify in a self-directed team project. The "default" path for this project is to modify the provided model to make their own abstraction choices, in order to answer a scientific question related to disease spread. We presented modeling the Meme Game as an advanced option; this requires students to re-interpret the mathematics of the model to represent different physical phenomena. We saw 3 of 37 teams choose this option.

One team that modeled the Meme Game chose to set aside the provided agent-based SIR model and devise their own modeling approach. The students chose to directly model the "three-card deck" of the Meme Game and randomly update the graph representing connectivity to represent mixing in the game. This demonstrates a conceptually distinct way to model the Meme Game—an approach we did not consider prior to running this iteration of the course. The students used this model to assess whether the qualitative behavior observed in the real game—the "rise-and-fall" behavior of certain memes—could be achieved without explicit differences in meme desirability; their results are shown in Figure 7. This student work demonstrates that authentic abstraction work is possible among undergraduate students.

In addition to asking students to critically consider these different approaches to modeling, we invite students to modify these models as they see fit or develop entirely new models. This is aligned with the cultural shift called for by Ravetz [28] wherein students grow from mere recipients of scientific knowledge to active participants in its creation. Developing this pathway to participatory modeling experiences in a first-year experience helps us broaden participation in the process of science.

Implications

It has been suggested that undergraduates lack the relevant domain knowledge to participate authentically in the full modeling process [1], [8]. While this may be true for modeling highly-specialized phenomena—such as structural mechanics—our results suggest that some first-year undergraduate students can engage in the full modeling process—for the proposed domain. Given our methods, we cannot establish the rate or degree to which students can perform this kind of work. However, we did observe several student teams conduct self-directed abstraction work to build a new model for the Meme Game. Future work should probe the generalizability of this finding.

We suggest that the overlapping space of social “infectivity” (e.g., meme spread) and disease transmission is a particularly rich context for educational activities, even in engineering curricula. We believe this space is under-explored: A recent scoping review sought to determine how often infectious disease is taught in the K-12 space; they found that educational studies on this topic are rare, and suggest that this is a ripe space for educational work [23]. Our particular approach was to highlight connections between disease and misinformation spread in a broader effort to teach the modeling process. Other educators can consider this conceptual space to serve their own learning goals.

On the other hand, the relative rarity of epidemiological study in K-12 suggests a relatively “level” playing field for first-year, first semester engineering students. One tension we have found with prior incarnations of our course (which previously focused on traditional engineering topics, such as heat transfer and mechanics) is that students would enter with vastly different levels of preparation, which adversely affected equity in our classroom. If all students enter the class with similar levels of domain knowledge, this may support equity in the classroom.

The misinformation / virality analogy (and the Meme Game in particular) is a useful entry point for early students, as elements of social media and misinformation are ubiquitous in the present culture. In contrast with population-level epidemiology, social media dynamics are likely to be familiar to almost all modern students. The success of our activity suggests that explicitly incorporating the form and process (instead of simply the content) of activities already commonplace in students' lives can prime interest and inject a spirit of scientific inquiry into the otherwise-mundane.

Prior research on "participatory simulations" [14] akin to the Meme Game have explored the use of technology in such educational activities. Our design for the Meme Game explicitly excludes technology for the activity's duration. Further, we suggest that collecting data in a low-technology fashion is particularly effective at making *validation* and data analysis transparent. The transparency in instrumentation in our game—performed by students with pen-and-paper—lies in contrast to physical experiments where instrumentation is performed by black box technology, e.g. a data acquisition unit. We hypothesize that this transparency of instrumentation may encourage students to engage with validation more deeply, though future work is necessary to assess this hypothesis.

Conclusions

We designed an interactive, hands-on activity as the focal point for an experience introducing the process of modeling. The activity—the "Meme Game"—is simple to play, rich in its outcomes, and instrumented to support model validation. As demonstrated through two successful deployments engaging over 100 undergraduate engineering students, the Meme Game leverages ideas from epidemiology to create an engaging introductory experience which motivates diverse approaches to quantitative modeling and enables experiences in validation with its rich set of results. This work presents a promising avenue for inviting early engineering students to develop their engineering judgment by participating directly in the modeling process.

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References

[1] C. Haines and R. Crouch, "Mathematical modelling and applications: Ability and competence frameworks," in *Modelling and applications in mathematics education: The 14th ICMI Study*, New York: Springer, 2007, pp. 417–424.
[2] L. English and B. Sriraman, "Problem solving for the 21st century," in *Theories of mathematics education: Seeking new frontiers*, Berlin/Heidelberg: Springer-Verlag, 2010, pp. 263–290.
[3] R. Lesh and J. Zawojewski, "Problem solving and modeling," in *Second handbook of research on mathematics teaching and learning*, Charlotte, NC: Information Age Publishing, 2007, pp. 763–804.
[4] F. Lester and P. Kehle, "From problem solving to modeling: The evolution of thinking about research on complex mathematical activity," in *Beyond constructivism: Models and modeling perspectives on mathematics problem solving, learning, and teaching*, Mahwah, NJ: Lawrence Erlbaum Associates, 2003, pp. 501–517.
[5] H. W. Coleman, W. G. Steele, and H. W. Coleman, *Experimentation, validation, and*

uncertainty analysis for engineers, 3rd ed. Hoboken, N.J: John Wiley & Sons, 2009.

[6] A. J. Keane and P. B. Nair, *Computational Approaches for Aerospace Design: The Pursuit of Excellence*, 1st ed. Wiley, 2005. doi: 10.1002/0470855487.

[7] A. Downey, *Modeling and Simulation in Python*. 9 Washburn Ave Needham MA 02492: Green Tea Press, 2017. [Online]. Available: https://greenteapress.com/modsimpy/ModSimPy3.pdf

[8] J. Gainsburg, "Learning to Model in Engineering," *Math. Think. Learn.*, vol. 15, no. 4, pp. 259–290, Oct. 2013, doi: 10.1080/10986065.2013.830947.

[9] J. Gainsburg, "The Mathematical Disposition of Structural Engineers," *J. Res. Math. Educ.*, vol. 38, no. 5, pp. 477–506, 2007.

[10] R. Rogers, "Planning for independent software verification and validation," in *3rd Computers in Aerospace Conference*, San Diego,CA,U.S.A.: American Institute of Aeronautics and Astronautics, Oct. 1981. doi: 10.2514/6.1981-2100.

[11] O. Balci, "Verification, Validation, and Testing," in *Handbook of Simulation*, J. Banks, Ed., Hoboken, NJ, USA: John Wiley & Sons, Inc., 1998, pp. 335–393. doi: 10.1002/9780470172445.ch10.

[12] W. L. Oberkampf and M. F. Barone, "Measures of agreement between computation and experiment: Validation metrics," *J. Comput. Phys.*, vol. 217, no. 1, pp. 5–36, Sep. 2006, doi: 10.1016/j.jcp.2006.03.037.

[13] H. T. Lingefjärd, "Mathematical modeling by prospective teachers using technology," University of Georgia, 2000. [Online]. Available: https://getd.libs.uga.edu/pdfs/lingefjard_henry_t_200005_phd.pdf

[14] E. Rosenbaum, E. Klopfer, and J. Perry, "On Location Learning: Authentic Applied Science with Networked Augmented Realities," *J. Sci. Educ. Technol.*, vol. 16, no. 1, pp. 31–45, Feb. 2007, doi: 10.1007/s10956-006-9036-0.

[15] R. Lesh, M. Hoover, B. Hole, A. Kelly, and T. Post, "Principles for developing thought-revealing activities for students and teachers," in *Handbook of Research Design in Mathematics and Science Education*, Mahwah, NJ: Lawrence Erlbaum, 2000, pp. 591–645.

[16] H. A. Diefes-Dux, J. S. Zawojewski, M. Hjalmarson, and K. Bowman, "Quantifying Aluminum Crystal Size Part 1: The Model-Eliciting Activity," *J. STEM Educ.*, vol. 7, no. 1 & 2, pp. 51–63, 2006.

[17] M. Somerville *et al.*, "The Olin Curriculum: Thinking Toward the Future," *IEEE Trans. Educ.*, vol. 48, no. 1, pp. 198–205, Feb. 2005, doi: 10.1109/TE.2004.842905.

[18] M. Hjalmarson, H. A. Diefes-Dux, K. Bowman, and J. S. Zawojewski, "Quantifying Aluminum Crystal Size Part 2: The Model-Development Sequence," *J. STEM Educ.*, vol. 7, no. 1 & 2, pp. 64–73, 2006.

[19] L. Wang and B. C. Wood, "An epidemiological approach to model the viral propagation of memes," *Appl. Math. Model.*, vol. 35, no. 11, pp. 5442–5447, Nov. 2011, doi: 10.1016/j.apm.2011.04.035.

[20] D. Gruhl, R. Guha, D. Liben-Nowell, and A. Tomkins, "Information diffusion through blogspace," in *Proceedings of the 13th international conference on World Wide Web*, New York NY USA: ACM, May 2004, pp. 491–501. doi: 10.1145/988672.988739.

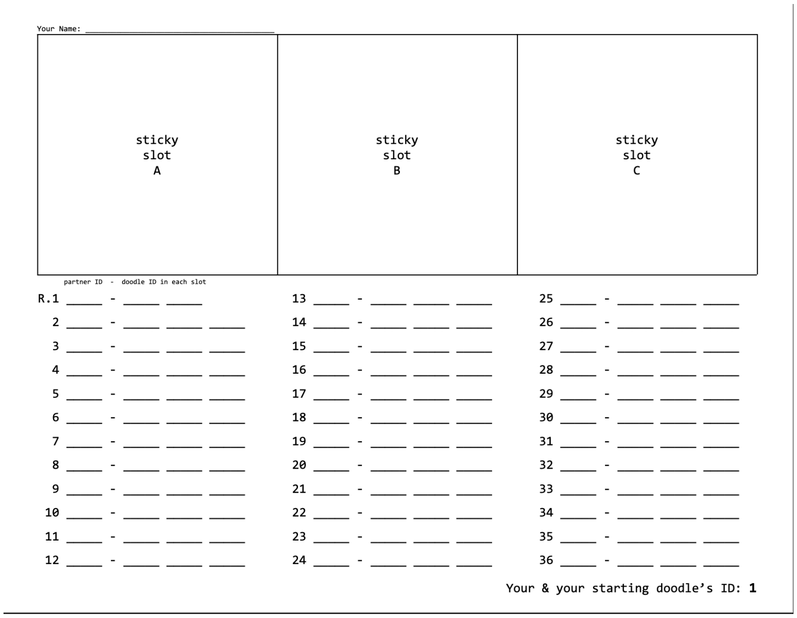
[21] X. Wei, N. C. Valler, B. A. Prakash, I. Neamtiu, M. Faloutsos, and C. Faloutsos, "Competing Memes Propagation on Networks: A Network Science Perspective," *IEEE J. Sel. Areas Commun.*, vol. 31, no. 6, pp. 1049–1060, Jun. 2013, doi: 10.1109/JSAC.2013.130607.

[22] A. Saltelli *et al.*, “Five ways to ensure that models serve society: a manifesto,” *Nature*, vol. 582, no. 7813, pp. 482–484, Jun. 2020, doi: 10.1038/d41586-020-01812-9.
[23] Y. B. Kafai, Y. Xin, D. Fields, and C. Tofel‐Grehl, “Teaching and learning about respiratory infectious diseases: A scoping review of interventions in K‐12 education,” *J. Res. Sci. Teach.*, vol. 59, no. 7, pp. 1274–1300, Sep. 2022, doi: 10.1002/tea.21797.
[24] J. Case and G. Light, “Emerging research methodologies in engineering education research,” *J. Eng. Educ.*, vol. 100, no. 1, pp. 186–210, 2011.
[25] A. Deaton and N. Cartwright, “Understanding and misunderstanding randomized controlled trials,” *Soc. Sci. Med.*, vol. 210, pp. 2–21, Aug. 2018, doi: 10.1016/j.socscimed.2017.12.005.
[26] M. Martcheva, *An introduction to mathematical epidemiology*. in Texts in applied mathematics, no. Volume 61. New York Heidelberg Dordrecht London: Springer, 2015. doi: 10.1007/978-1-4899-7612-3.
[27] E. B. Wilson and J. Worcester, “The Law of Mass Action in Epidemiology,” *Proc. Natl. Acad. Sci.*, vol. 31, no. 1, pp. 24–34, Jan. 1945, doi: 10.1073/pnas.31.1.24.
[28] J. Ravetz, “Stop the science training that demands ‘don’t ask,’” *Nature*, vol. 575, no. 7783, pp. 417–417, Nov. 2019, doi: 10.1038/d41586-019-03527-y.

Appendices

A1. The Meme Game - Datasheet and Data entry template

Student participants in the Meme Game enter their results each round in a “datasheet”, shown in Figure 8. Students are given a printed copy of their datasheet, where each datasheet contains a unique identifier. After the game has completed, students are directed to transcribe their paper datasheet to a digital copy. This enables convenient analysis of the Meme Game’s dynamic state.



Your Name: ____

sticky slot A

sticky slot B

sticky slot C

partner ID - doodle ID in each slot

R.1 ____ - ____ ____
2 ____ - ____ ____ ____
3 ____ - ____ ____ ____
4 ____ - ____ ____ ____
5 ____ - ____ ____ ____
6 ____ - ____ ____ ____
7 ____ - ____ ____ ____
8 ____ - ____ ____ ____
9 ____ - ____ ____ ____
10 ____ - ____ ____ ____
11 ____ - ____ ____ ____
12 ____ - ____ ____ ____
13 ____ - ____ ____ ____
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29 ____ - ____ ____ ____
30 ____ - ____ ____ ____
31 ____ - ____ ____ ____
32 ____ - ____ ____ ____
33 ____ - ____ ____ ____
34 ____ - ____ ____ ____
35 ____ - ____ ____ ____
36 ____ - ____ ____ ____

Your & your starting doodle’s ID: **1**

Figure 8. The Meme Game datasheet; a printed copy of this sheet is given to each participant.

The following link is for the Meme Game datasheet, with 100 unique IDs:
https://docs.google.com/document/d/13RqBkT4KfVCsnl1Yp19yQR21RVaq2JCetLOuwvB7ee4/edit?usp=sharing

The following link will allow you to make a copy of the Google sheet used for data entry:
https://docs.google.com/spreadsheets/d/1N-ozgFHQc_pAtb1ItfqDn1zt2g7ifd0_ZZDA7-4b_xQ/copy#gid=0