A Gamified Applied Mathematics Curriculum Structure for Developing the Semiconductor Manufacturing Workforce

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Abstract

We describe herewith an applied mathematics curriculum structure for developing the semiconductor manufacturing workforce through a gamified approach, centering data science. Gamification is a powerful tool to engage students collaboratively and individually in mathematical content that is relevant and necessary for industry. Centering the curriculum on data science not only teaches skills and develops understanding, but it also improves computational, algorithmic, and inferential thinking – valuable skills for the future workforce. The proposed curriculum utilizes two gamification models, the Capture the Flag (CTF) model and the Try Hack Me (THM) model. The curriculum also incorporates a two-stage case study model to develop and reinforce the reasoning and communication skills necessary for success in the semiconductor manufacturing industry. The case studies will be sourced from industry partners for verisimilitude and to ensure alignment with real-world industry concerns.

Background

Industry partners have noted that the students in the current High School and Community College programs for Semiconductor Manufacturing are not always developing the logic and problem-solving skills necessary for successful integration in industry and career advancement. The existing curriculum tends to engage students with mathematical skills, but the relevance of these skills is often unclear to students. As a result, students may lose motivation and end their programs of study before completion. In response, we aim to develop an applied math curriculum which leverages gamification to encourage and develop problem solving relevant to the students and to the industry.

Proposed Approach

Gamification of Mathematics

One approach to curricular design that increases students' perceptions of the relevance of a content while also building problem solving and logic skills is to gamify the content. "Games give people a chance to learn at their own pace, take risks, cultivate deeper understanding, fail and want to try again--right away--and ultimately, succeed in ways that too often elude them in school." [8]. Learning math through games can encourage students to shed the 'non-math person' identity and take on the success and failure of their gamified self (often an avatar).

Gamification is not simply learning via technology. As early as 1958 the USA was providing technology-delivered lessons, but the focus was to judge right and wrong in specific consistent behaviors. Learning was limited to positive or negative reinforcement of responses. An incorrect response would result in looking at the same material again or receiving a parallel question to try. This approach is still largely the technology-driven lesson approach available in K-14 mathematics programs.

Gamification is often misconstrued as a behaviorist learning framework. In a gamified approach, the judgment is not merely right or wrong, but preferable or less preferable to get to the desired "win." The idea is not to simply remember / retain the content, but rather discover and puzzle in order to gain the skills and understandings needed to succeed. Failure is expected and desired, as failing forward is the expected process for success [8].

Gamifying the mathematics used in semiconductor manufacturing training is intended to not only produce the deeper mathematics learning through data and data-based decision making, but also to produce the curiosity and problem-solving dispositions necessary for this industry.

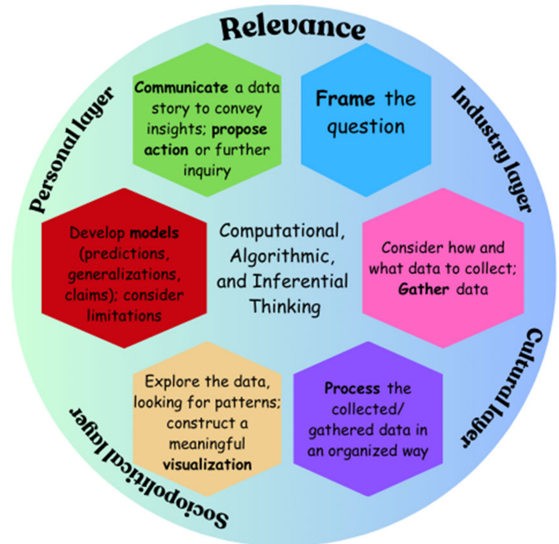
The proposed gamified curriculum uses design principles found in the data science framework [5] alongside three different models, a Capture the Flag (CTF) model, a Try Hack Me (THM) model, and a Case Study model. Each model provides benefits necessary for success, and taken together, the curriculum addresses all the learning needs for success in semiconductor manufacturing careers.

Data Science Framework

The proposed Applied Mathematics curriculum design centers data science, with critical data analytics tools. The data science framework (Figure 1) situates three critical types of thinking as central to the data process – (i) computational, (ii) algorithmic, and (iii) inferential thinking. The data science framework is *not a series of steps*, but rather includes stages of data science that produce the most robust understanding of the situation and the most informed decisions possible. These stages, coupled with the three types of thinking, are approached through relevant contexts or lenses that may come from industry, personal, cultural, or sociopolitical layers [5].

The data science framework starts by framing the question(s). The participant(s) discuss how and what data must be collected and /or gathered. The relevant data are then collected/gathered and cleaned and processed in an organized way. The data collection and cleaning are done primarily with Excel, ensuring students develop spreadsheet skills for the workplace. The processed data is explored for patterns and schema using data exploration and data visualization techniques. Excel provides various visualization tools, and it interfaces with Power BI for more interactive visualizations. Predictive models are then developed, and generalization claims are made, while attending to limitations and constraints. A data story is communicated to convey insights with a proposed action plan or further inquiry. It is important to note that the start and the end of this sequence is situated in the relevance layer, specifically leveraging inferential thinking around industry contexts.

Figure 1: Data Science Framework.

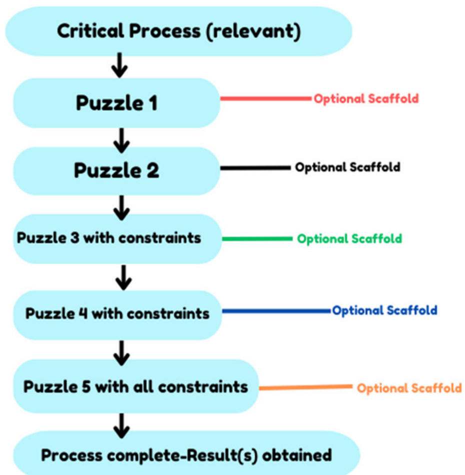


Gamification Model 1 - Capture the Flag (CTF)

The objective of this model is to learn a critical process relevant to the semiconductor manufacturing industry. The semiconductor sector needs a workforce that understands specific processes and can use these processes regularly. Gamification lies in scaffolding the learning of critical processes into puzzles. This model (shown in Figure 2) engages learners as a team. In this depiction of the model a critical process is broken down into five puzzles, although these processes may be introduced with a varied number of puzzles throughout the curriculum. The learner must develop acuity in each of the five pieces of a complete process, which in turn provides the learner the ability to engage in the entire process in the real-world. Excel and Power BI will be leveraged heavily in this model, which will improve students' understanding of and use of these critical tools. To help the learner focus on each part of the process, constraints that occur in the real-world application of the process are gradually introduced. Initially the puzzles should have minimal or no constraints. This allows the learner to begin developing the skills and understandings required to think through the simplest stages of the process being learned. The next puzzles should gradually introduce more constraints and more complex constraints. The final puzzle should represent the final stage of the relevant process and have all the constraints necessary to understand the process in depth. Additionally, students can select scaffolds for any puzzle in the form of hints and extensions in order to progress after struggle has become unproductive. These scaffolds come at a "price," decreasing the points earned from solving puzzles. As a result, students can, and generally do, choose to retry the

CTF puzzles again without scaffolds. This creates a new experience with greater complexity, encouraging increased levels of autonomy and developing a deeper and more robust understanding of the critical process being learned.

Figure 2: The CTF Model.



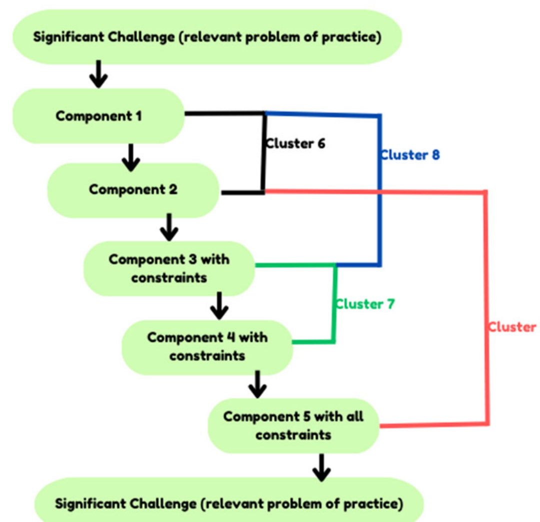
Since the solution path is ambiguous or underspecified, student thinking is enhanced and becomes flexible. Students tend to become more autonomous, imaginative, and initiative through this CTF gamified model. As a result of solving each puzzle gradually, students achieve concrete incremental success, thus increasing motivation and confidence. The CTF model provides natural feedback while students are puzzling, which builds perception-action schema [2]. According to Prabawa et al, 2017, this gamification model has a significant effect on the comprehension skills of the students. Further, it also helps transition the teacher's role from lecturer to facilitator in a student-centered learning environment [6].

Gamification Model 2 - Try Hack Me (THM)

The objective of this model is to learn how to overcome a significant and complex challenge common to the semiconductor manufacturing industry. This model, represented in Figure 3, engages learners in a partnership or in a team. Each significant challenge is divided into components, grouped into clusters of components, and includes the complete challenge in its full complexity. Each component requires the learner to develop increasingly advanced Excel skills. After solving individual components, students will tackle stages that include clusters of components. Components include the gradual introduction of relevant constraints, and constraints increase gradually in complexity to finally include all typical constraints. Clusters also provide learners the opportunity to use advanced Excel techniques in concert with visualization capabilities to improve analysis of the situation and understand how these techniques and visualizations work together. The final stage of this model, unlike the CTF model, has all the constraints necessary for the significant challenge and includes a cluster of all the components of the significant challenge. In this final stage, learners will need to leverage all the Excel techniques developed throughout the challenge in order to be successful.

By combining different components as clusters, to form a new component stage, the learning experience is enhanced, and the experience also more closely approximates a challenge faced in semiconductor manufacturing. Figure 3 depicts each component 1-5 individually before combining components 1 and 2, components 3 and 4, components 1-3, and components 2-5, before providing the complete challenge with all five components and all possible constraints.

Figure 3: The THM Model.



This model retains the complexity of the challenge while building the respective component skills systematically. It also provides concrete success indicators that the learner perceives as increased expertise. Each successful component earns the learner a badge, named for the Excel skill(s) and the industry context. Each successful cluster also earns the learner a badge. The final badge is earned by the successful completion of the entire challenge and the successful integration of the advanced spreadsheet skills. The badges serve to motivate the learner, help the learner name and identify the skills developed, and elevate the learner's identity as a problem solver and increase their confidence in their own expertise and understanding.

The learner views the learning as interesting, useful, and relevant. The clustered components add an extra dimension of nuance to the challenge and enhance the learner's problem solving and logical thinking, helping the learner recognize the advanced understandings gained. This model is designed on the premise that to achieve the greatest learning results, the game platform should provide skills both isolated and alongside other skills [1,7].

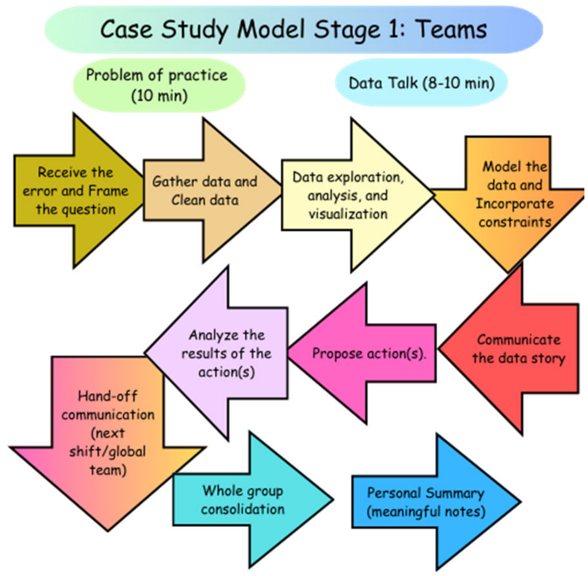
Case Study

In a case study approach, the focus includes problem-based learning elucidated in a case study format the requires Excel formulas, analytics, visualizations, and coding. This requires a focus on problem solving using the case study and a focus on both students and instructors explaining concepts through consolidating the new learning resulting from engaging in the case study. A robust case study model includes five interactions: students with students, students with the instructor, students with technology, students with learning materials (the case study and relevant resources), and students with communities (the relevant industry community via the case study or via accessible Subject Matter Experts (SMEs). With case study, the learning process moves from a single person (instructor) to a shared responsibility among students, within students, and among the classroom community [4]. The case study model includes two distinct stages.

Case Study Model -Stage 1: Teams

In this approach, students are divided into small teams. Figure 4 details Stage 1. Each team receives the case study problem statement and frames the question(s). They gather and clean the relevant data using Excel. At the next stage, each team explores and analyzes the clean data through data visualization and data modeling techniques using both Excel and Power BI. After data modeling, appropriate constraints are incorporated into the model to build a data story. The team discusses and communicates the results of the data story to propose actionable recommendations, using Excel to justify the decisions. Further, the actions are analyzed. This entire process and the results throughout are communicated to the next team. The instructor leads the whole group through a consolidation routine based on the work of the teams. The consolidation routine will inspect how teams used Excel and Power BI, what decisions were made, how these decisions were supported by the analyses and visualizations, which assumptions were made, and the results attained. The goal of the consolidation routine is to make all the thinking and decisions visible, as well as to spotlight the use of tools and analyze how well these choices worked. At the end of the whole-group consolidation, each individual student takes meaningful notes as a personal summary of their learnings.

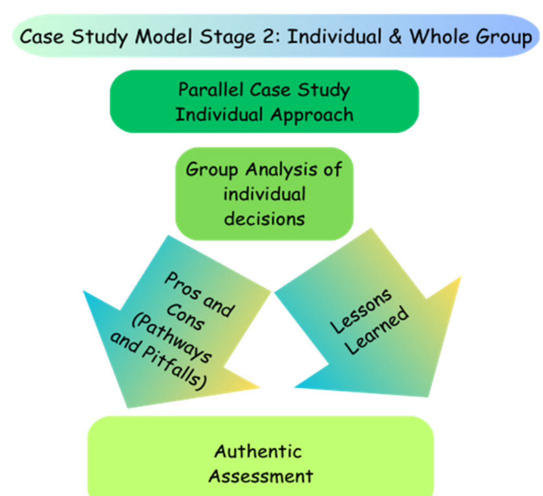
Figure 4: Case Study Model Stage 1.



Case Study Model - Stage 2: Individual and Whole Group

In this stage, each student is provided a parallel case study individually to solve, as opposed to the previous approach involving teams (see Figure 5). Once the individuals complete their analysis and response, the whole group then discusses and analyzes their individual decisions, their interpretations, the techniques used with Excel and Power BI, and the ideas/rationale behind their approach. The class will discuss pathways and pitfalls to each approach and the lessons learned during a whole group discussion. The discussion concludes with an individual authentic assessment of the concepts learned and the tool techniques developed.

Figure 5: Case Study Model Stage 2.



Conclusion

Data science is a relevant framework with which to reinforce the applied mathematics content necessary for the semiconductor manufacturing industry. Centering the mathematics content in data science provides the process through which learners can come to understand the mathematics ideas and develop the skills while also developing computational, algorithmic, and inferential thinking, all necessary skills for successful employment in the semiconductor manufacturing industry. These three ways of thinking together also address a critical industry need, employees' greater problem solving and logical thinking. By delivering this applied mathematics through two game structures, Capture the Flag and Try Hack Me, alongside a Case Study framework, students are motivated and learn how to work together and analyze individually to solve relevant challenges and learn necessary processes for semiconductor manufacturing. By affording students' time and experiences to develop robust understandings and skills with Excel and Power BI, students will have advanced expertise in the tools leveraged in this and other industries. The gamification of semiconductor manufacturing applied mathematics content situated in a data science framework while developing spreadsheet expertise directly responds to the challenges currently faced by both the semiconductor manufacturing industry and students learning semiconductor manufacturing, positioning learners to become a highly successful and skilled workforce for this industry.

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