Types of Models Identified by First-Year Engineering Students

Dr. Kelsey Joy Rodgers, Embry-Riddle Aeronautical University-Daytona Beach

Kelsey Rodgers is an assistant professor in the Engineering Fundamentals Department at Embry-Riddle Aeronautical University. She teaches a MATLAB programming course to mostly first-year engineering students. She primarily investigates how students develop mathematical models and simulations and effective feedback. She graduated from the School of Engineering Education at Purdue University with a doctorate in engineering education. She previous conducted research in Purdue University's First-Year Engineering Program with the Network for Nanotechnology (NCN) Educational Research team, the Model-Eliciting Activities (MEAs) Educational Research team, and a few fellow STEM education graduates for an obtained Discovery, Engagement, and Learning (DEAL) grant. Prior to attending Purdue University, she graduated from Arizona State University with her B.S.E. in Engineering from the College of Technology and Innovation, where she worked on a team conducting research on how students learn LabVIEW through Disassemble, Analyze, Assemble (DAA) activities.

Dr. Angela Thompson P.E., University of Louisville

Dr. Angela Thompson is an Associate Professor in the Department of Engineering Fundamentals at the University of Louisville. Dr. Thompson received her PhD in Mechanical Engineering from the University of Louisville. Her research interests are in biomechanics and engineering education, particularly related to first-year students.

Dr. Matthew A. Verleger, Embry-Riddle Aeronautical University-Daytona Beach

Matthew Verleger is an Associate Professor of Engineering Fundamentals at Embry-Riddle Aeronautical University in Daytona Beach, Florida. His research interests are focused on using action research methodologies to develop immediate, measurable improvements in classroom instruction and on the development of software tools to enhance engineering education. Dr. Verleger is an active member of ASEE, having served as the founding chair of the Student Division, a Program Chair and a Director for the Educational Research and Methods Division, and the General Chair of the First-Year Division's First-Year Engineering Experience Conference.

Dr. Farshid Marbouti, San Jose State University

Farshid Marbouti is an Assistant Professor of General (interdisciplinary) Engineering at San Jose State University (SJSU). Dr. Marbouti completed his Ph.D. in Engineering Education at Purdue University. His research interests center on First-Year Engineering student success, engineering design, and learning analytics.

Mr. Nishith Shah
Pujan Thaker, Embry-Riddle Aeronautical University-Daytona Beach

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Abstract

This is a Complete Research paper. Understanding models is important for engineering students, but not often taught explicitly in first-year courses. Although there are many types of models in engineering, studies have shown that engineering students most commonly identify prototyping or physical models when asked about modeling. In order to evaluate students' understanding of different types of models used in engineering and the effectiveness of interventions designed to teach modeling, a survey was developed. This paper describes development of a framework to categorize the types of engineering models that first-year engineering students discuss based on both previous literature and students' responses to survey questions about models. In Fall 2019, the survey was administered to first-year engineering students to investigate their awareness of types of models and understanding of how to apply different types of models in solving engineering problems. Students' responses to three questions from the survey were analyzed in this study: 1. What is a model in science, technology, engineering, and mathematics (STEM) fields?, 2. List different types of models that you can think of., and 3. Describe each different type of model you listed. Responses were categorized by model type and the framework was updated through an iterative coding process. After four rounds of analysis of 30 different students' responses, an acceptable percentage agreement was reached between independent researchers coding the data. Resulting frequencies of the various model types identified by students are presented along with representative student responses to provide insight into students' understanding of models in STEM. This study is part of a larger project to understand the impact of modeling interventions on students' awareness of models and their ability to build and apply models.

Introduction

Engineering requires the use of many types of models to understand, evaluate, and make predictions about systems [1, 2]. Models can be developed using various types of tools and for many different purposes [3]. Although there are many types of models used in engineering, studies have shown that engineering students most commonly identify prototyping or physical models when asked about modeling [1]. Additionally, students are often unaware that models may be used to make predictions. Previous studies have found that modeling interventions can significantly increase students' understanding of mathematical models and the use of models to make predictions [1, 2, 4].

Some types of models embedded in engineering curriculum, industry, and research are: physical models, prototypes, Computer-Aided Design (CAD) models, engineering sketches, mathematical models, statistical models, computational models, computer simulations, project management models, risk assessment models, and financial models. Additionally, there is some overlap in these types of models. There are also many applications for these models, as well as processes for developing and refining them. The purpose for developing or applying a model could be educational, explorative, instructional or many other reasons [5. This is also confounded by how specific disciplines of engineering utilize different types of models. For example, in software engineering there are user-interaction models, which are unique to this field [5]. The purpose behind and domain-specific models are beyond the scope of this paper. For this study, five model categories were utilized which provided a broad perspective of major model types: physical, virtual/graphical, mathematical, computational, and financial/business models.

Physical models represent a class of models that translate to tangible objects, such as prototypes. Most commonly students think of modeling in a physical nature, so it is most difficult to expand students' ideas beyond this one type of modeling [2]. Some engineering courses focus on utilizing physical models, such as prototyping as part of the design process, but neglect to incorporate any explicit materials related to the concept of modeling.

Virtual or graphical models are visual representations of physical systems, such as 3D modeling through CAD and 2D engineering sketches. Many CAD and 3D parametric modeling engineering courses typically focus on learning specific CAD package's environments and commands rather than the use of CAD as a modeling tool [6]. The emphasis is typically not about purposeful design to model and analyze more complex physical systems. There have been some promising results when modeling and the use of tangible objects are used to facilitate CAD courses [6].

Mathematical models are abstracted, mathematized, and quantified representations of a real-world system that are developed through an iterative process of model refinement [3, 7]. Mathematical models are implicitly embedded throughout various engineering courses, but rarely explicitly taught [2]. A pedagogical approach that has been extensively studied to enable students to develop mathematical modeling skills is the use of Model-Eliciting Activities (MEAs) [8, 9]. MEAs are a type of open-ended problem where students create a mathematical model to meet particular criteria and constraints for a stakeholder based on provided, relevant data [1]. While MEAs have demonstrated success across a broad spectrum of characteristics (e.g., improved retention of women, increased experience with peer review, improved professional skills attainment), adoption of MEAs can be challenging, in part because MEAs are time consuming to meaningfully implement and evaluate, as well as initially design and develop [10-12]. Not only is there a lot of resistance for faculty buy-in, many students complain about the workload required to complete the activities. In part of this larger project, the team has worked on utilizing the Models and Modeling Perspective (M&MP) design principles and MEAs to develop and implement modeling problems in an introductory programming course. The use of both mathematical and computational modeling as a framework to help students develop programs to solve engineering problems has shown some promising results [13, 14].

Computational models, as defined in this study, focus on the implementation of mathematical models through computer applications [3]. One commonly used type of computational model is a simulation [15-19]. Simulations are a type of program that enables a user to interface with an underlying model [18]. Simulations are used in educational settings by challenging students to interact with an existing simulation (e.g., [17]) or challenging students to build a simulation (e.g., [12]) [18]. Computational modeling is also taught is in the context of programming courses (e.g., [19]), but in this setting it is rarely referred to as computational modeling or a simulation. For example, having students develop code that can respond to a variety of input conditions is a computer model, but is typically referred to as "programming logic". The previously mentioned interventions [13, 14] present examples of computational modeling language integrated throughout a programming course. This is another place where modeling is commonly implicitly implemented and could be explicitly incorporated. There is also relevant research within the Computational Adaptive Expertise (CADEX) framework [20] and research around computational thinking [21] that discuss computational modeling.

Financial and business models were incorporated in this study to address the need for more engineers with entrepreneurial awareness and skills [22]. Some examples of business models are competitive analysis models and risk analysis [22].

Research Purpose and Questions

As part of a larger research effort to evaluate the effectiveness of various interventions on student's understanding of models in first-year engineering courses, the team developed a survey to assess student awareness and understanding of different types of models. The primary goal of this study was to develop a framework to categorize the types of models that first-year engineering students discuss in response to the survey, as well as ideas that they commonly hold about models in STEM. This framework will be used to analyze students' responses about types of models at various points in their academic careers.

The broader research questions that drove this project are: (1) What types of models do first-year engineering students identify when prompted to describe models in STEM fields? and (2) How do students label and describe types of models in STEM fields?. The purpose of this paper is to describe the iterative development of the framework used classify the types of models students identified.

Methods

Setting and Participants

This research is part of a multi-institutional study on the impact of different modeling interventions in first-year engineering courses. This study involves three universities that all have a collection of first-year engineering courses. Some descriptive information about the universities, the college of engineering degrees offered, student demographic information, and the collection of first-year engineering courses are presented in Table 1.

Table 1. Summary of Descriptive Information about Three Institutions in Study

Uni.	Descriptive Information	First-Year Engineering (FYE) Course/s
1	**University:** Medium-sized, private, STEM+Business university **COE Degrees:** Aerospace, Civil, Mechanical, Electrical, Computer, and Software Engineering **COE Demographics (Fall 2019: n=2,308):** *Gender:* 76.5% men, 23.5% women *Race/Ethnicity/Nationality:* 59% White, 14% Hispanic/Latinx, 5% Asian, 4% Black, 5% two or more races, 10% International	1. Introduction to Design (2 cr. hrs.) 2. CAD Course (3 cr. hrs.) 3. Programming Course (3 cr. hrs.)

2	**University:** Large-size, public school **COE Degrees:** Aerospace Engineering, Aviation and Technology, Biomedical Engineering, Chemical and Materials Engineering, Civil and Environmental Engineering, Computer Engineering, Electrical Engineering, General Engineering (Interdisciplinary), Industrial and Systems Engineering Mechanical Engineering **COE Demographics (Fall 2019: n=6,831):** *Gender:* 75% men, 25% women *Race/Ethnicity/Nationality:* 33% Asian, 16% Hispanic/Latinx, 13% White, 29% International	1. Introduction to Engineering (2 cr. hrs.)
3	**University:** Large, public R1 university **COE Degrees:** Bioengineering, Chemical, Civil, Industrial, Mechanical, Electrical, Computer Science and Engineering **COE Demographics (Fall 2019: n=2,700):** *Gender:* 76.5% men, 23.5% women *Race/Ethnicity:* 71% White, 7% Asian, 5% Black, 4% Hispanic/Latinx, 4% two or more races	1&2. Engineering Methods, Tools, and Practice I and II (2 cr. hrs. each)

The three universities each incorporated different types of modeling interventions that required different levels of revision of the existing courses (described in Table 2). The intervention at University 1 involved the development of a modeling learning community and required the most changes and therefore would require the most effort and teacher buy-in to adopt. The intervention at University 3 would likely require the least amount of changes to the course and ideally present a more accessible intervention, which focused on making implicit modeling throughout the course explicit. Some of the specific interventions in the Programming Course at University 1 are discussed in previous studies [13, 14].

Table 2. Summary of Modeling Interventions at Three Institutions in Study

	Modeling Intervention	First-Year Engineering (FYE) Courses Revised
University 1	• Development of Engineering Models Learning Community (EMLC) • Courses in EMLC were revised to ensure students built and applied physical, virtual, financial, mathematical, and computational models multiple times across all courses • Modeling language was integrated throughout	All three FYE courses (Design, CAD, Programming courses)
University 2	• One design project was revised to ensure physical, virtual, mathematical, computational, and financial models were incorporated • Modeling language was integrated throughout	Lab portion of the only first-year engineering course
University 3	• Course materials were revised to integrate modeling language explicitly anywhere it was implicitly being covered	Engineering Methods, Tools, and Practice I

Data Collection

A modeling survey was developed based on existing literature on modeling in engineering and feedback from a collection of modeling experts (i.e. external evaluators). The purpose of the survey was to investigate students' awareness of different types of models and how to apply different models to solve engineering problems. The full survey is provided in Appendix A.

In Fall 2019, the modeling survey was first administered to investigate students' awareness of types of models and understandings of how to apply different types of models in solving engineering problems at two universities (Universities 1 and 2). In Fall 2020, it was administered to all 3 universities. At University 1 it was administered across all sections of the CAD and Programming Courses. Only a few of these sections were involved in the modeling intervention. At University 2 and University 3 the survey was only administered to the section/s that implemented the modeling intervention. The surveys were implemented in the courses as a class assignment at the beginning (pre) and end (post) of the semester.

Table 3. Summary of Students that Completed Modeling Survey

	Fall 2019	Spring 2020	Fall 2020	Spring 2021
University 1, FYE CAD Course	Enrolled: 437 Pre: 237 Post: 147	Enrolled: 309 Pre: 213 Post: 73	Enrolled: 377 Pre: 236 Post: 99	Enrolled: 357 *data collection in progress*
University 1, FYE Programming Course	Enrolled: 375 Pre: 359 Post: 201	Enrolled: 431 Pre: 424 Post: 241	Enrolled: 432 Pre: 417 Post: 302	Enrolled: 419 *data collection in progress*
University 2, FYE Design Course	Enrolled: 25 Pre: 23 Post: 22	N/A	Enrolled: 25 Pre: 25 Post: 24	N/A
University 3, FYE Course	N/A	N/A	Enrolled: 570 Pre: 338 Post: 298	N/A

The data collected in Fall 2019 was used for this portion of the study (to develop the framework). Students' responses to the first three questions about modeling in the survey were analyzed in this study (Q3-Q5):

Q3. What is a model in science, technology, engineering, and mathematics (STEM) fields?
Q4. List different types of models that you can think of.
Q5. Describe each different type of model you listed.

Data Analysis

This study involved the development of a framework to analyze the types of models first-year engineering students identified in response to the modeling survey. The team began with a deductive analysis of students' responses based on existing literature [23]. The initial framework started with five types of models: physical, virtual/graphical, mathematical, computational, and financial/business models. A sixth option was “none” for none of the listed types of models. More codes were developed based on an inductive analysis of components that were not captured by the six initial codes determined [23]. The goal of coding with this framework was to determine the types of models students were aware of based on description, application, name, etc. – not evaluating students ability to state specific names for models.

Since the goal of the study was to determine the types of models students identified, the researchers initially only analyzed students’ response to Q4 (list types of models you can think of). Five researchers on the team individually analyzed the 22 students’ pre and post responses collected in Fall 2019 at University 2 (n = 45 student responses). After each researcher determined the types of models based on the initial framework, the whole team met to discuss the similarities and differences in our coding, as well as aspects of students’ responses that were not captured in the initial framework. Based on discussions, there were two major revisions: (1) Questions 3-5 were analyzed instead of only Questions 4 to better understand the types of models students were discussing with more context and (2) an “undetermined” category was added to the framework. The “none” category was further described to only pertain to responses that had no content related to STEM models. The “undetermined” category was incorporated to capture students’ responses that appeared to discuss some type of STEM-relevant model, but there was not enough context to decipher the type. The team also noted the importance of considering the context of the courses the students took. For example, if students discussed wind turbines as models after designing prototypes of them in class, then these could be considered identification of physical models.

Three of the five researchers (i.e. two undergraduate student researchers and a professor) then individually analyzed 40 students’ responses of the pre and post data from the two courses at University 1 using the updated framework. The three researchers came to a consensus and then further discussed any concepts not captured by the applied framework. The team consistently noticed examples of students discussing types of data representation (such as charts and graphs), but not presenting enough information to classify them as a specific type of model nor a generic example of modeling that could not be categorized (undetermined). As a result, an additional category was established called “data representation”.

After these exploratory rounds of analysis to search for emergent themes, there were four formal rounds of coding to meet an acceptable intercoder reliability measurement on all categories. The percentage agreement for each category had to be at least 80% to be considered acceptable [24]. The percentage agreement calculated for each category and round is shown in Table 4.

Each round, two undergraduate student researchers individually analyzed 30 students’ responses from University 1 that were not previously analyzed; there were 15 responses analyzed from each of the two courses. After each round a third researcher would meet with the student researchers to facilitate discussion and resolve disagreements. The biggest variability across the reviewers throughout the intercoder reliability process was inferring a type of model versus selecting undetermined due to insufficient information to decipher the type of model. The business or financial model category was included in this framework based on literature, but this was the least coded category.

On the third round both researchers noted a pattern of students specifically writing theoretical or conceptual models and there was uncertainty about which models these would fall under. The team noticed some of the discrepancies in the undetermined category and other specific types of models was related to the coding for conceptual and theoretical models. Upon further analysis of the relevant student responses, the team added a final (ninth) category to the framework – "theoretical/conceptual models". This separate category was created since there were many instances where students specifically wrote "conceptual model" or "theoretical model".

Table 4. Intercoder Reliability Measurement – Percentage Agreement

Round	Physical	Virtual/ Graphical	Mathematical	Computational	Financial	Undetermined	Theoretical/ Conceptual	Data Representation	None
1	**67.7%**	87.1%	96.8%	93.5%	100.0%	**74.2%**	N/A	90.3%	83.9%
2	90.0%	80.0%	96.7%	96.7%	100.0%	**70.0%**	N/A	86.7%	100.0%
3	80.0%	90.0%	86.7%	93.3%	100.0%	**66.7%**	N/A	100.0%	90.0%
4	93.3%	86.7%	96.7%	93.3%	100.0%	83.3%	93.3%	96.7%	100.0%

NOTE: Bold, red numbers represent areas where rater agreement was insufficient.

Following the fourth round of coding and sufficient intercoder reliability (Table 4), the two undergraduate researchers independently coded separate parts of the data. To further ensure reliability throughout the coding process, there were weekly meetings where the researchers would highlight students' responses that they were unsure about and the three researchers would hold a discussion to determine the appropriate codes. Throughout this process, different examples were noted to track the common languages and examples grouped under each category (see Table 5 for a complete list of these keywords).

Table 5. Keywords for each Coding Category

Physical	prototype, scale/scaled/scaling down version of structure/plane/something that is physical (like a model plane or model car), 3-D printing (not 3-D modeling) (relevant examples from courses at the university – University 1: model rockets; University 2: wind turbine)
Graphical/ Virtual	virtual models, CAD (Computer-Aided Design), CATIA, SolidWorks, SolidEdge, 3-D modeling, engineering drawings, drawing, sketches, Inventor, Sketchup, Fusion 360, AutoCAD, 2D, 3D, any 2D or 3D thing (other than 3-D printing or 3-D plot), 3D printouts (drawings), blueprints, diagram, maps
Mathematical	formulas, equations, math, calculations, algorithm, flowcharts, process representation
Computational	computer program, simulation, code, coding, MATLAB, java, python, C++, Excel, (relevant examples from courses at University 1: Trajectory spreadsheet, Stage Optimizer MATLAB code)
Business/ Financial	money, finances, cost, budget, project management, etc.
Undetermined	only if an additional category potentially and we cannot determine the category it would fit into; an example of things that cannot be deciphered into a type of model: computer-based modeling (could be graphical/virtual or computational model), mock-ups (could be physical or graphical/virtual); if both/all potential categories are already coded, then undetermined is not coded; if explanation provides enough context to select a type of model, then it is coded under the relevant type of model
Theoretical/ Conceptual	only if they explicitly state conceptual/concept or theoretical model AND it is not described by the student well enough to fall into another category (these would normally fall in undetermined, so this can be considered a specific type of undetermined)
Data Representation	graphs, tables, types of graphs, mind map, Venn diagrams
None	No STEM models defined (e.g., "I don't know", role models)

Coded results (frequencies of the model types identified by students) in the collective pre and post Fall 2019 data are presented in addition to some representative student responses.

Findings

Previous research has shown that many engineering students focus on Physical Models over other types of models [2]. A similar pattern was seen throughout this analysis. Physical and Graphical/Virtual Models were the two most commonly identified models in the students' survey responses at both universities when looking across all the pre and post data collected (see Figure 1). The students discussed graphical/virtual models the most in the CAD Course. The students mentioned mathematical models more in the Programming Course and Design Course. The students discussed computational models most in the Programming Course. The students presented ideas about business or financial models most in the Design Course.

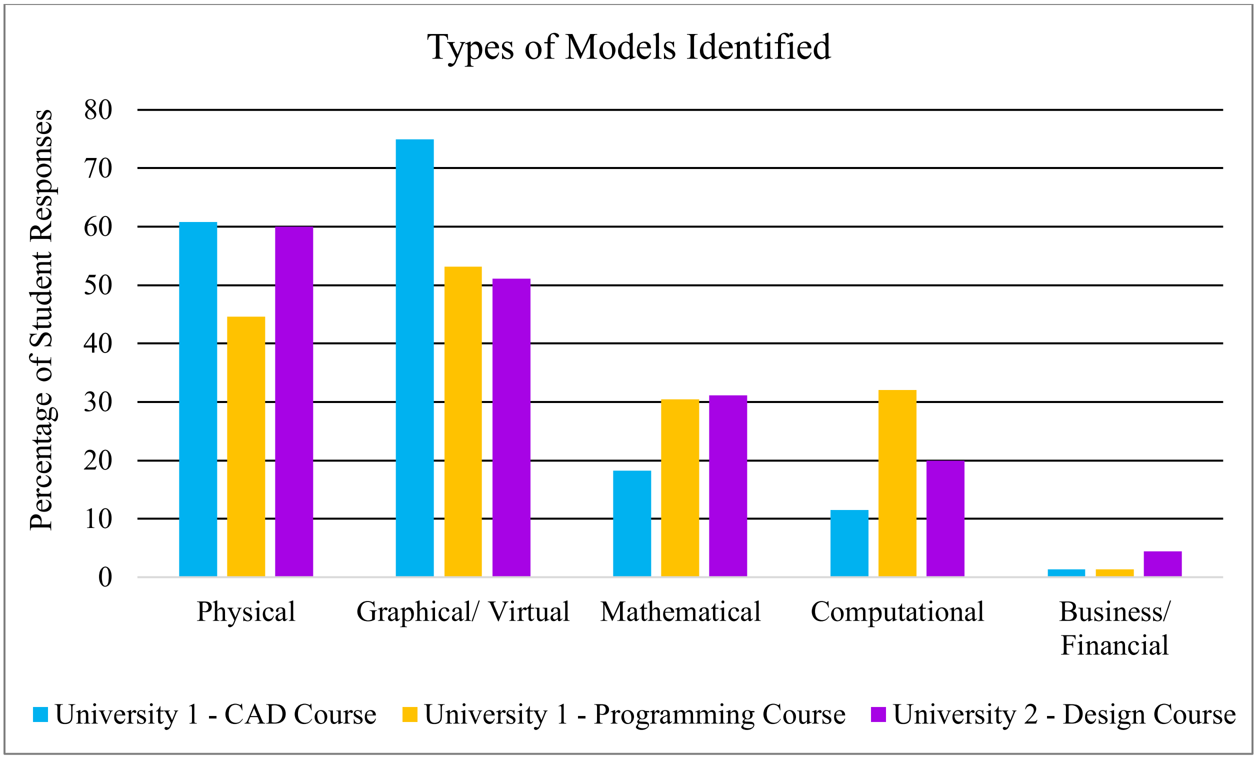

Figure 1. Analysis of Students' Responses to Fall 2019 Survey

There were three main categories of responses identified in the analysis regarding students' ability to use modeling language and provide descriptions. Students either:

(a – see Table 6) both labeled the type/s of model/s and clearly described them,
(b – see Table 7) labeled the type/s of model/s, but could not describe them, or
(c – see Table 8) explained a type/s of model/s, but could not label them.

The presented coding scheme did not capture these differences, so this could not be quantified. The students' abilities to name and interpret types of models should be further investigated. Since many students could not clearly label types of models (Q4), the surrounding survey questions (Q3, Q5) were critical in categorizing their responses and also helped further validate the coded categories.

Table 6. Sample Students' Responses – clearly identified types of models with description

Responses to Questions			Codes
Q3	Q4	Q5	
a representation of a person, thing or proposed structure typically on a smaller scale.	physical models conceptual models mathematical models	1. smaller and simpler representations of the thing being modeled 2. ties ideas together to explain an event 3. sets of equations that takes into account many factors	Physical, Conceptual, and Mathematical Models
A scaled version of something	CAD models, rapid prototype models	3D models designed on the computer through computer software, physical printed models such as 3D printing	Physical and Graphical/Virtual Models

NOTE: Both these students' responses were collected in the pre-survey at University 1 (the first student in the CAD Course and the second student in the Programming Course).

Table 7. Sample Students' Responses – clearly identified types of models without description

Responses to Questions			Codes
Q3	Q4	Q5	
models may be used to analyze a system to find solutions to particular problems.	Computer, visual, and mathematical	I am unsure/ not knowledgeable on information.	Mathematical, Computational, and Undetermined Models

NOTE: This student's response was collected in the pre-survey at University 2.

Table 8. Sample Student's Response – description without clear labels

Responses to Questions			Codes
Q3	Q4	Q5	
It could be a problem that uses coding to "model" a solution. The model is not a physical or 3D model that would normally be thought of.	Coding models	In the coding model, you are given a question that you have to answer as well as several givens. Using the information provided and possibly some researched information, you create a code that can helps solve the problem.	Mathematical and Computational Models (not Physical, and Graphical/ Virtual Models)

NOTE: This student's response was collected in the pre-survey at University 1 in the Programming Course.

The sample student response shown in Table 8 presents a type of model that would be categorized as a Computational Model based on the coding scheme, but their further explanation makes it more clear that they are discussing both Mathematical and Computational Models. This is an example of one place where additional codes would be missed without more context that can be found by analyzing their response to the fifth question. Another strange component of their response is this student clearly stated that Physical and Graphical/Virtual Models are not examples of STEM models. This is unlike the typical first-year engineering student that most commonly identifies physical models. The student could potentially be explaining the type of model they are discussing is not one of these models, but they acknowledge these are also models. There are many responses such as this one that demonstrate a need to further investigate students' understandings of types of models through a more qualitative approach – e.g., student interviews – to capture their ideas more in depth.

There were also some students that only presented examples of models (rather than types of models) in response to the fourth question, so their responses to the surrounding questions were even more critical. Table 9 shows two students' responses where they provided different examples for types of models instead of actual labels. Their explanations in the other questions made the categorization of the types of models clearer.

Table 9. Sample Students' Responses – explaining their examples

Responses to Questions			Codes
Q3	Q4	Q5	
A model is something (an object) that represents something else that is bigger.	Cars, planes, trains, buildings, etc.	A model plane would be a plane that is related to the actual size, but is much smaller and the dimensions are in someway proportional to the actual plane. The same applies for cars, trains, and buildings. The model is just a much smaller representation of something that is from the real world, with the dimensions being in someway proportional.	Physical Model
A model in the STEM fields is a 3d rendering that is used for reference or a template	A city plan & a model car	A city plan can be a 3d design on a computer of cubes and other shapes that represent buildings, trees and sidewalks. A model car can be a real scaled metal model of a Toyota Prius	Physical, and Graphical/ Virtual Models

NOTE: Both these students' responses were collected in the pre-survey at University 1 in the CAD Course.

Throughout the coding process a few interesting patterns were noted that should be further investigated. For example, many students specifically wrote "Conceptual" or "Theoretical" Models (refer to Table 6 for an example). This was not a category the team expected to include, but was elicited in the students' responses. These responses were only seen from students in University 1. There were 14 students (2.5%) that mentioned conceptual or theoretical models in the Programming Course and 19 students (5.0%) in the CAD Course. There was not a large percentage of students that stated these ideas and a much smaller sample size at University 2, so the smaller sample size could have been the reason it was not found at both universities.

Another elicited category was data representation. These responses occurred at the highest frequency amongst students in the Design Course at University 2 (20% of students' responses). At University 1, it was more frequent in the Programming Course (15.4%) than the CAD Course (12.5%). Two students' responses regarding data representation are shown in Table 10. The first student discussed data representation, but did not go any further to meet the requirements for any type of model. Some students did present information regarding various types of models in addition to discussing data representation, such as the second student did in their response. The students that discussed data representation may have the potential to further these concepts to begin to identify mathematical models.

Table 10. Sample Student's Response – data representation

Responses to Questions			Codes
Q3	Q4	Q5	
Something that represents data in a readable way	Bar graph, pie chart, histogram	A bar graph represents data in bars to compare one variable. A pie chart does the same thing, but represents data in a circle instead. A histogram is used to represent the frequency	Data Representation
A model is the framework for a project so that the engineer knows exactly what they are trying to accomplish before actually doing it.	Physical, graphical, coding	Physical - a tangible object representing a larger object. Graphical - a graph representing data. Code - a coding model to frame the objectives of a program.	Physical and Computational Models, Data Representation

NOTE: The first student's response was collected at University 2 in the pre-survey for the Design Course. The second student's response was collected at University 1 in the post-survey for the Programming Course.

There were also some interesting findings that were not captured in the established framework that should be further investigated. It was found that students typically focused on things being scaled down when discussing both Physical and Graphical/Virtual Models. There weren't many examples found where students discussed using models to scale up something smaller. This concept of scaling when applying models should be further investigated, especially with the on-going further emphasis on micro- and nano-technologies to address societal needs. Table 11 shows two students' responses with these different perspectives of scaling. The first student discussed modeling things that are either scaled down or actual size – not scaling up. Some previous students' responses also further demonstrate this (e.g., both students' responses in Table 9). The second student discussed using models to scale a smaller object up, specifically cells. Their response about the cell model could have been either be a Graphical/Virtual or Physical Model, so it was coded as an Undetermined Model.

Table 11. Sample Students' Responses – models and scaling

Responses to Questions			Types of Models
Q3	Q4	Q5	
A model is a display of a certain creation in order to show what it is like.	Miniature model, full scale model. 3D model	Miniature model can be a small version of something that is big. A full scale model is a actual size of what the creation will be. a 3D model is a rendering of whatever the creation is on a computer.	Physical, and Graphical/ Virtual Models
visual representation of a larger item, usually used for planning or explaining items	Business models, Fashion Models, and Cell Models.	Business Model: A plan/outline for the operation of a business. Fashion Model: Individual that represents a designers clothing by showcasing them. Cell Model: An enlarged replica of a cell often used to inform individuals	Business/ Financial and Undetermined Models

NOTE: The first student's response was collected at University 2 in the pre-survey for the Design Course. The second student's response was collected at University 1 in the pre-survey for the Programming Course.

The second student's comment about "Fashion Models" also demonstrates another concerning pattern that was found in some students' responses. The team specifically prompted students to discuss and identify models in the STEM fields to mitigate responses such as this. Table 12 presents an assortment of four students responses collected at the beginning of the semester at University 1. All the responses were coded as None because they did not present any coded types of models. These demonstrate some of the different types of things engineering students may consider models used in STEM fields that are not the right idea. The students were informed that they could write "I don't know" if they were unsure about any of the questions to receive full credit for completing the survey, so there was no requirement to write something if they were unsure. These responses prompt the need for further investigation into potential misconceptions that students may have about engineering models.

Table 12. Sample Students' Responses – all coded "None"

Responses to Questions		
Q3	Q4	Q5
Bill Gates	Role Model Hero	A role model is someone who leads by example and shows what is right and wrong by their actions. A Hero is someone you look up to maybe its because what they do is something you want to do or its because they inspirer you.
Robotics is a great model of the STEM fields, because it incorporates all of those disciplines.	Robotics	Robotics is a very cool model as it incorporates all the STEM disciplines. Robotics is a branch of technology that incorporates design, construction, operation, and utilization of robots.
Models are tools used to help teach basic knowledge of an idea in STEM	Presentations, Informative visual videos	For presentations a prime example is a professor going step by step through how to code or do something whether it be mathematically, code based, ect. Informative visual videos is similar to Presentations in regards to going step by step through the process
A model in the stem field is a Major area or concentration.	Gaming Consoles, Cars, Phones	A gaming console is used for playing games having fun with friends and family reconnecting to a different setting. Cars are a source of transportation that we use today to get around from place to place. Phones are used in this generation almost EVERYDAY!!!! Phones are a source of communication that we use today to reconnect with others. Social media ,text ,call, etc. It's a mini computer in your pocket that you take everywhere you go.

NOTE: All students' responses were collected in the pre-survey at University 1. The first three students were enrolled in the Programming Course. The last student was enrolled in the CAD Course.

Conclusions

As discussed, these findings show various types of models that first-year engineering students identified and some other ideas that were either not quite engineering models or far off of the correct concepts. This study presents a survey that can be administered to elicit students' ideas about types of models and a framework to help interpret their responses. Some of the frequencies were presented in this study, but further analysis of the pre-survey responses compared to the post-survey responses are presented in some of our prior research [24, 25].

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Appendix A. Modeling Survey

This survey is administered through Qualtrics. It does not allow students to go back after they click next on each block (blocks are noted below). All questions require the students to at least input some text or select an option. All demographic information was collected at the end in hopes to help mitigate stereotype threat. When the survey is administered, students are told not to use additional resources – example: "These questions are to capture what you know about models coming into this course, so you may not use the internet or discuss with others to answer these questions."

<block 1>
Question 1. Name:
Question 2. University Email:

<block 2>
Questions 3-5.

What is a model in science, technology, engineering, and mathematics (STEM) fields?

List different types of models that you can think of.

Describe each different type of model you listed.

<block 3>
Questions 6 & 7.

What are models used for? (check all that apply)

- ☐ to make a decision based on a hunch or gut feeling
- ☐ only for examining theoretical concepts
- ☐ to represent an idea, system, object, or system
- ☐ to make predictions
- ☐ to test theories
- ☐ to make evidence-based decisions

What is the relationship between physical and graphical models?

- ○ Physical models and graphical models are the same.
- ○ Physical models are based on graphical models.
- ○ Physical models and graphical models are both visual representations of a system.
- ○ Physical models and graphical models are not related.
- ○ Graphical models are based on physical models.

<block 4>
Question 8.

What is the relationship between mathematical and computational models?

- ○ Computational models are based on mathematical models.
- ○ Mathematical models are the same as computational models.
- ○ Mathematical models are based on computational models.
- ○ Mathematical models and computational models are not related.

<block 5>
Question 9.

You have been asked to determine where to install a solar energy power plant. You were provided weather data for some different locations and land area purchase prices. Think about how you would approach this problem.

What types of models would you use? (check all that apply)

- ☐ None
- ☐ Physical Models
- ☐ Graphical Models
- ☐ Computational Models
- ☐ Mathematical Models
- ☐ Financial Models
- ☐ Other ______

<block 6>
Question 10.
Students are prompted to describe how they would use each type of model they select in the previous question. This consists of no additional prompts if the student selected "None" in response to Question 11 or up to 6 separate prompts, if they selected all 5 listed models and "Other".

Briefly describe (1-2 sentences) how you would use [type] Models.

<block 7>
Question 11.

You have been asked to design a chair that can be folded flat and stacked when not in use. You've been given data on material costs, weight requirements, and typical chair dimensions. Think about how you would approach this problem.

What types of models would you use? (check all that apply)

- ☐ None
- ☐ Physical Models
- ☐ Graphical Models
- ☐ Computational Models
- ☐ Mathematical Models
- ☐ Financial Models
- ☐ Other ________

<block 8>
Question 12.
Students are prompted to describe how they would use each type of model they select in the previous question. This consists of no additional prompts if the student selected "None" in response to Question 11 or up to 6 separate prompts, if they selected all 5 listed models and "Other".

Briefly describe (1-2 sentences) how you would use [type] Models.

<block 9>
Questions 13-17.
Demographic information collected. Select (an) option/s from a list. Questions 13 & 14 have a blank to fill in additional information as well. Questions 13-16, students can select a prefer not to say option.

Question 13. Gender
Question 14. Race/Ethnicity
Question 15. International Student status
Question 16. Class Standing
Question 17. Additional information about their degree and/or college. (question varies across institutions)