First-Year Engineering Students' Understanding and Application of Models: Comparing Impact of CATIA vs. MATLAB Courses

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Abstract

To succeed in engineering careers, students must be able to create and apply models to certain problems. The different types of modeling skills include physical, mathematical, computational, graphing, and financial. However, many students struggle to define and form relevant models in their engineering courses. We are hoping that the students are able to better define and apply models in their engineering courses after they have completed the MATLAB and/or CATIA courses. We also are hoping to see a difference in model identification between the MATLAB and CATIA courses. All students in the MATLAB and CATIA courses must be able to understand and create models in order to solve problems and think critically in engineering. Students need foundational knowledge about basic modeling skills that will be effective in their course. The goal is for students to create an approach to help them solve problems logically and apply different modeling skills.

Keywords

First-Year Engineering, Models and Modeling, CATIA, MATLAB

Introduction

Although there are many types of models used in engineering, engineering students typically think about physical models rather than other model types (e.g., mathematical and theoretical models).[1] Further contributing to this, many engineering courses tend to represent models as a physical concept.[1] In addition to this, modeling is rarely explicitly taught in engineering courses.[1,2] Also, in the world, models are represented as physical objects, such as miniature model planes or miniature solar system models. As a result, based on their experiences, many students tend to perceive models as just physical.[1] Although these models play an important role in engineering, it is important for engineering students to develop an ability to create and apply various types of models in engineering. As a precursor to creating and applying different types of models, it is important that students have an awareness of different models utilized in engineering.

Research Questions

The research questions investigated in this study were: (1) What types of models do engineering students identify prior to and after completing a first-year engineering course? and (2) How do students' responses compare across two different courses (CATIA and MATLAB courses)? Additionally, we looked at demographic data to determine if there were differences across gender. Other demographics were considered, but not evaluated due to small sample sizes.

Literature Review

Models represent systems using a variety of interacting representational media.[3] As previously stated, physical models and prototypes are the most common types of models that engineering students are familiar with. Most physical models neglect mathematical components that represent behaviors.[4] Other types of models used in engineering that were explored in this study are mathematical, computational, virtual, and financial models. The models of most interest were mathematical, computational, and virtual models based on the context of this study.

Mathematical models are significant in engineering as they describe how a certain model works. Mathematical models are difficult as many students do not understand how mathematics relates to real world problems, so they struggle in seeing how it can be useful in modeling.[1] The use of mathematical modeling is important for students to promote problem solving and improve their logical thinking when solving an engineering problem.[1,3,5] Very few students considered mathematical models before a modeling intervention, but after learning the importance of mathematical modeling, students' responses discussing mathematical models increased by 79%.[1] Model-eliciting activities (MEAs) are one mathematical modeling intervention that have been heavily utilized and researched in engineering education.[5]

Computational modeling in engineering is important as computational modeling allows one to test simulations, make autonomous programs, and is practiced widely in all sorts of fields.[1] Computational modeling is seen from weather channels to wind tunnel testing. One common type of computational model used in engineering is simulations.[6] Virtual models is a general term used throughout this paper for computer assisted design (CAD), engineering drawings, and various forms of 2D and 3D models designed on computers or paper. Carberry and McKenna (2014) included CAD drawings and computer simulations under computer models; they found that students' responses about computer models decreased by 20% from pre- to post-.[1]

Methods

Setting and Participants

This study was conducted within two of the first-year engineering courses at a STEM+Business, private university in the fall of 2019. Most engineering students at this university are required to complete three first-year engineering courses: (1) an introduction to engineering design course (Design course), (2) an introduction to computer programming for engineers course (MATLAB course), and (3) an introduction to graphical communications course (CATIA course). The courses are described in Table 1.

Table 1. First-Year Engineering Courses

Course	Credit Hours	Course Description
Design	2	This course introduces students to the engineering profession. Students actively learn the design process by participating in two to three team design projects, typically focused on space or aviation-related systems. Professionalism and ethics within engineering are topics that are covered throughout the course.
MATLAB	3	This course introduces students to programming computers. Students will explore solutions to problems that can be solved using a computer and learn to plan out the needed programs. The programming language used for this course is MATLAB.
CATIA	3	This course is designed to teach students visualization skills, hand sketching and parametric modeling. Students are introduced to CATIA, a CAD program predominately used in the aerospace industry.

Students can take the three courses at different times and in different orders/combinations, but most students complete all three courses in the first year since they are prerequisites to their future engineering courses. The students cannot complete all the courses in the same semester though, since they are not allowed to take the MATLAB and CATIA courses at the same time without approval. Other limiting factors are: the MATLAB course has a co-requisite of Calculus 1, the CATIA course requires performing sufficiently high of the Purdue Spatial Visualization Test: Rotations (PSVT:R)[7], and the Design course has a similar number of seats in the fall and spring available (so not everyone can enroll in the fall semester).

In Fall 2019, there were a total of 600 students enrolled in the MATLAB and CATIA course; no students were enrolled in all three first-year courses and only two students were enrolled in both the MATLAB and CATIA courses. Out of the 365 students enrolled in the MATLAB course, 235 were only enrolled in the MATLAB course and 128 were also enrolled in the Design course. Out of 335 students enrolled in the CATIA course, 191 were only enrolled in the CATIA course and 142 were also enrolled in the Design course. These numbers do not include students that enrolled in the courses and dropped before the drop/add date a few weeks into the semester (meaning the course does not show up on their transcript).

All the first-year courses at this university are taught in smaller sections of students averaging 20-25 students per section. The sections of the Design course have different types of modeling at varying degrees integrated in them depending on the instructors and projects they implement; the impact of this course was not the focus of this study. In Fall 2019, six instructors taught 18 sections of the MATLAB course and seven instructors taught 14 sections of the CATIA course. The integration of models and modeling language varies across the sections in both these courses depending on the instructor. All the MATLAB sections require students to complete a modeling problem with multiple submissions that prompts them to develop a mathematical and computational model. These are discussed more in previous studies.[8,9] The nature of the CATIA course is a strong emphasis on physical models and virtual models (e.g., hand sketching, 2D and 3D models, computer-aided design). Some instructors have greater emphasis on modeling language and discussion about how computational/numerical modeling can be done using their 3-D parametric modeling.

Data Collection

Students completed a survey at the beginning and end of the semester to determine their awareness and understanding of different types of engineering models. The Fall 2019 data analysis consisted of a total of 944 responses - consisting of 359 pre- and 201 post-survey responses for the MATLAB course (560 responses) and 237 pre- and 147 post-survey responses for the CATIA course (384 responses). Through the surveys, the team investigated what types of models students identified and how they would apply them.

The survey consisted of 15 questions. The first two questions were identifying information and the last five were demographic-related questions, as discussed in the following paragraphs. The remaining eight questions related to modeling. The first three modeling related questions asked students: 1) What is a model in science, technology, engineering, and mathematics (STEM) fields?, 2) List different types of models you can think of., and 3) Describe the different types of models you listed. Students' responses to these three questions was the source of data used for this study. After responding to each question, the student must click next and the survey locks so the students cannot go back to change their responses. The other questions asked about relationships between types of models and discussed theoretical scenarios prompting students to discuss how they would apply different types of models. These responses will be analyzed in future studies and are not in the scope of this study.

The majority of students in these courses (i.e., MATLAB and CATIA courses) were in the College of Engineering (COE). A small number of students enrolled in the courses were in the College of Arts and Sciences (COAS), College of Aviation (COA), and the College of Business (COB). The percentages of students' responses to the surveys are shown in Table 2 and are consistent with course enrollment rates by college.

Table 2. Survey Responses - Colleges (n = 560 and 384 responses)

Course	**COE**	**COAS**	**COA**	**COB**	**Blank**
MATLAB	84.8%	9.1%	5.4%	0.4%	0.4%
CATIA	95.3%	2.3%	0.5%	0.3%	1.6%

The majority of students in these courses are first-year students. The class standings of the students based on the survey responses to the pre- and post-surveys for both the MATLAB and CATIA courses are shown in Table 3. The MATLAB course had more students beyond the first-year class standing than the CATIA course; this could be due to more students taking the MATLAB course from other colleges and the MATLAB course having a higher drop, fail, and withdrawal rate at the university.

Table 3. Survey Responses - Class Standing (n = 560 and 384 responses)

Course	First-Year	Sophomore	Junior	Senior	Blank
MATLAB	59.3%	32.0%	5.4%	2.9%	0.5%
CATIA	89.6%	7.0%	1.8%	0.0%	1.6%

The students' self-reported gender is shown in Table 4 and their self-reported race and ethnicity is shown in Table 5. Also based on the survey responses, about 10% and 4% of students were International in the MATLAB and CATIA courses, respectively. Based on comparison to the institutional data, these numbers were representative of the students in the course.

Table 4. Gender (n = 560 and 384 responses)

Course	Male	Female	Other Responses*	Prefer Not to Say	Blank
MATLAB	69.8%	28.9%	0.2%	0.7%	0.4%
CATIA	83.6%	13.8%	0.5%	0.5%	1.6%
* Other Response includes Third Gender Variant Ze/Zer					

Table 5. Race/Ethnicity (n = 560 and 384 responses)

Course	Asian	Black	Hispanic/ Latinx	White	Other*	Two or More	Prefer Not to Say or Blank
MATLAB	9.8%	3.0%	10.0%	62.9%	1.6%	9.8%	3.2%
CATIA	7.3%	5.5%	6.3%	69.0%	1.8%	7.3%	3.4%
* Other Category includes Alaskan Native, Native American, Middle Eastern, and Other unspecified							

Data Analysis

Students' responses to the three questions about defining models and identifying/explaining types of models from the administered pre- and post- surveys were analyzed to determine the types of models they identified. The development of the framework utilized to analyze this data is discussed by Rodgers, Verleger, Marbouti, and Thompson (2021), as well the attainment of an acceptable intercoder reliability and other established measures to ensure reliability.[10]

The categories of model types in this coding scheme consisted of physical, mathematical, computational, virtual, and financial models. Sample types of these models found in students' responses are shown in Table 6. The other four established categories were undetermined, conceptual/theoretical models, data representation, and none. The undetermined category was used for content that presented an idea that could be a type of model, but it was indecipherable as to which based on the established categories. Conceptual/theoretical was used for general definitions of a model (e.g., "A model is a representation of data"). Data representation was used for specific methods of representing data that are not necessarily models (e.g., graphs, tables).

Table 6. First-Year Engineering Courses

Model Type	Examples from Students' Responses
Physical	Prototype, scaled down version of structures/vehicles, 3-D printing
Mathematical	Models using/containing formulas, equations, math, calculations, flowcharts
Computational	Models using/implemented through computer program, simulation, code/coding
Virtual	CAD, CAD software programs, engineering drawings, blueprints
Financial	Money, cost, budget

To determine whether there was a significant difference in the types of models identified by students at the beginning of the semester (pre-survey) and at the end of the semester (post-survey), a 3-way loglinear analysis was performed. The 3 factors included were survey (pre-or post), model type (physical, mathematical, computational, virtual, and financial), and whether each model was identified by the student (identified/not identified). Additionally, the total number of models identified by each student on each survey was determined. As data were non-normal, a Mann-Whitney U test was conducted to determine whether there was a significant difference in the mean number of models reported on the pre-survey vs post-survey.

To determine whether there was a significant difference in the types of models identified by students in each course (MATLAB vs CATIA), another 3-way loglinear analysis was performed. The 3 factors included were course, model type, and whether each model was identified by the student. Additionally, a Mann-Whitney U test was conducted to determine whether there was a significant difference in the mean number of models reported in each course. All statistical analysis was conducted in SPSS v26. Statistical significance was set at $p = 0.05$.

Based on the demographics in the survey data, there was a large enough number of female students to divide the data by gender to analyze the impact of the courses on students' awareness of types of models for females and males separately. There were not large enough sample sizes to analyze nationality, race/ethnicity, class standing, or college.

Findings

Upon entry to these two courses, physical and virtual models were the two most common model types students identified. There were differences in the types of models students identified across the MATLAB and CATIA courses for both the pre-and post-surveys. The loglinear analysis revealed significant interactions between pre/post-survey and model types identified (X^2 (df=4) =56.4, p<0.001) and between course and model types identified (X^2 (df=4) =151.1, p<0.001). Based on the percentage of students that identified each type of model, the largest change in percentage from pre-to post-in the MATLAB course were increases in the percentage of mathematical models and then computational models that were identified (Figure 1). The largest change in percentage from pre-to post-in the CATIA course were increases in the identification of mathematical and computational models, as well as data representation. In both courses, there were decreases in the percentage of students' responses that had no information and content that could potentially be discussing a type of model but was indecipherable. In the students' responses for the MATLAB course, there was also a slight decrease in the percentage of students that discussed physical models from pre-to post. This data is shown in Figure 1.

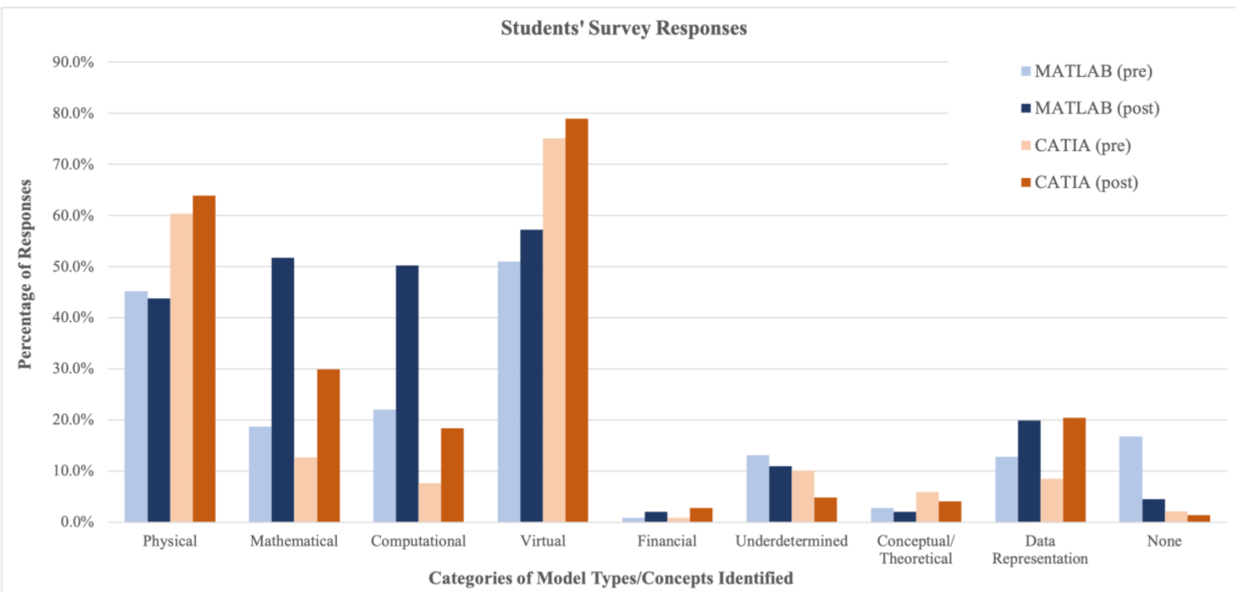

Figure 1. Graph of Students' Responses about Types of Models (CATIA vs. MATLAB)

The average number of models that the students identified in the pre-and post-surveys varied slightly as well. Physical, mathematical, computational, virtual, and financial models were counted as a type of model identified. In the pre-survey responses, students identified an average of 1.38 models in the MATLAB course and 1.57 models in the CATIA course. In the post-survey responses, students identified an average of 2.05 models in the MATLAB course and 1.94 models in the CATIA course. There was an increase in the average number of models identified by students from pre-to post-in both courses, but there was a greater increase in the MATLAB course than the CATIA course. Mann-Whitney U tests revealed a significant increase in the mean number of models reported from the pre-to post-survey (p<0.001) but no significant difference between the mean number of models reported in the 2 different courses.

The gender differences in the students' responses in the MATLAB course are shown in Figure 2. Although there was an overall decrease in the percentage of students that discussed physical models in the post-survey, there was a slight increase in females' responses. There was an increase in the percentage of students that identified mathematical and computational models from pre-to post-for both females and males. There was a larger increase in percentage for males than females for mathematical models and females than males for computational models. Although there was a larger percentage of females that identified mathematical models in the pre-survey, there was a larger percentage of males in the post-survey. There was a larger percentage of males that identified computational models in the pre-and post-surveys, even though there was a greater change for females. There was a greater percentage of males than females that identified virtual models, especially in the post-survey. There was a larger increase in the percentage of females that discussed data representation as a type of model from the pre-to post-survey. There was a larger percentage of females that did not discuss any models or relevant concepts (None category) in the pre-survey, but there was a larger percentage of males that had no content in the post-survey. Both groups had a decrease in the percentage of "None" responses.

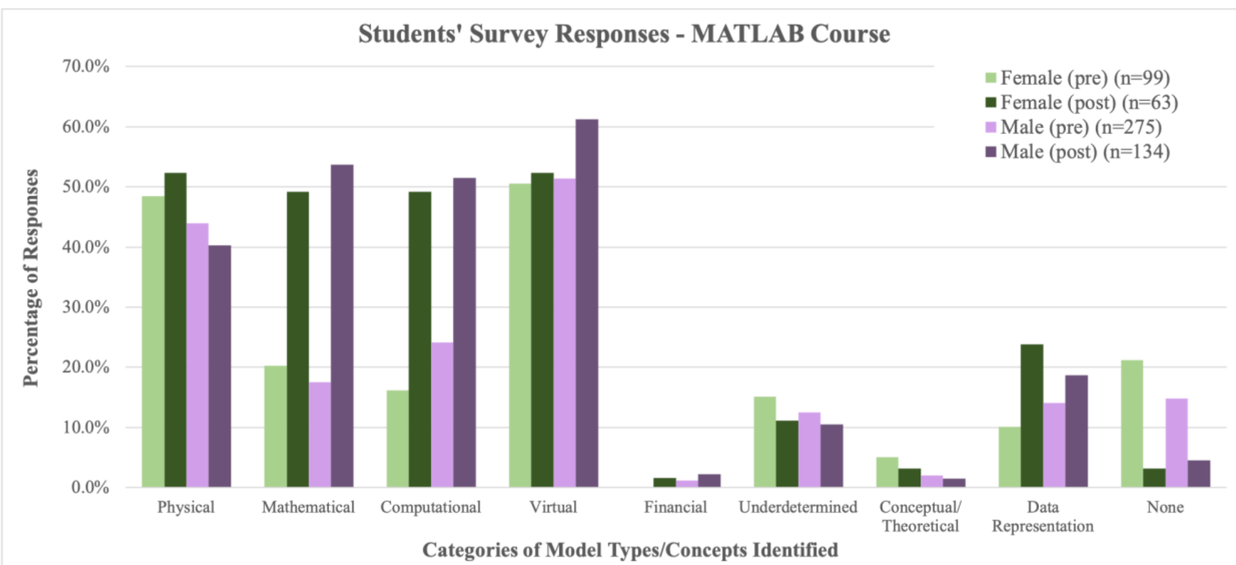

Figure 2. Students' Responses in MATLAB Course (Separated by Gender)

The gender differences in the students' responses in the CATIA course are shown in Figure 3. Similar to the MATLAB course data, the percentage of responses that identified physical models decreased for females and increased for males. There was a larger change from pre-to post-for females than males for the percentage of students that identified mathematical models in their responses. Although both groups had a higher percentage of students that identified virtual models in the pre-than the post-survey, females' responses had a larger increase. Similar to the data for the MATLAB course, the percentage of students' responses with content coded as "Undetermined" or "None" decreased for both groups, but decreased more for females.

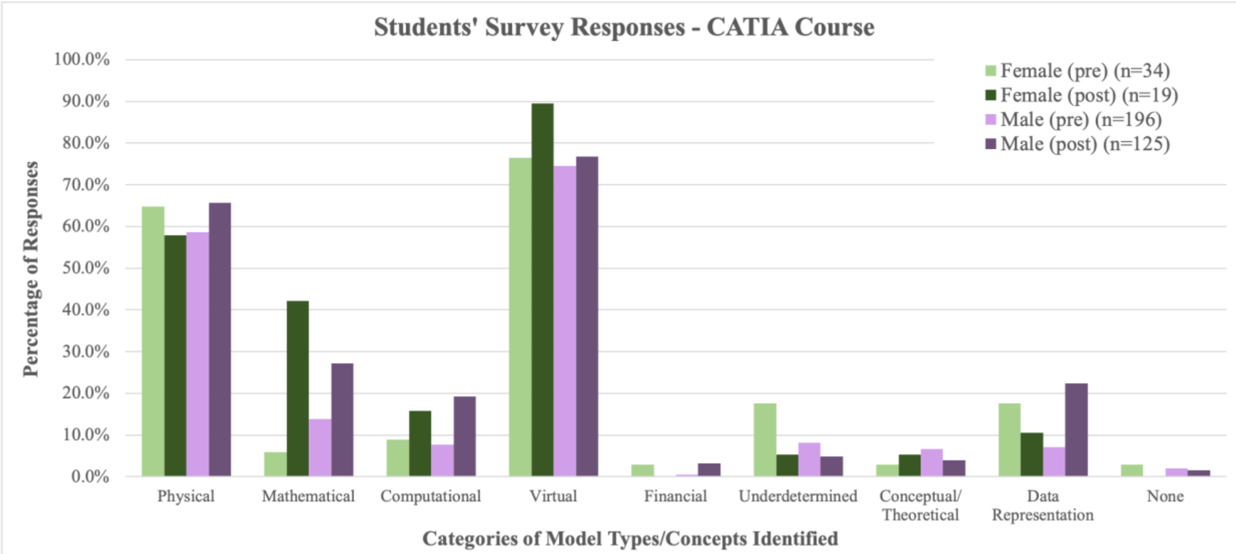

Figure 3. Students' Responses in CATIA Course (Separated by Gender)

Discussion

Types of Models Identified

Students tended to identify both physical and virtual models more than any other models in the beginning of the class. Due to prior experiences and education, students tend to typically think of modeling as physical in nature rather than mathematical and theoretical.[1] They also identified mathematical and computational models as well, but at a much lower percentage.

Upon completing the courses, students were able to identify more models on average, which demonstrated an increased awareness of model types. However, students in the MATLAB course had a larger increase in average number of models identified and demonstrated awareness of mathematical and computational models compared to the students in the CATIA course. For both courses, physical and virtual models did not see a large increase or decrease in identification. Although financial models were included in the framework, these were not identified by many students in the pre-or post-surveys. The decrease in undetermined models in both courses could demonstrate students' ability to better communicate ideas about specific model types. The increase in data representation across both courses should be further investigated. Data representation can be a component of simulations (i.e. computational models), so this may be a concept that should be explicitly discussed and linked to modeling. Previous research discussed first-year engineering students' confusion about components of simulations and visualization techniques in building a simulation.[11,12] Students' fragmented concepts about models that were captured in the undetermined, data representation, and none categories should be further investigated to ensure any potential misconceptions are mitigated and any partial ideas can be further built upon.

Differences Across Courses

After completing the MATLAB course, students identified mathematical and computational models more than the beginning of class. This relates to the fact that very few students considered mathematical models before a modeling intervention, but after learning the importance of mathematical modeling, students' responses discussing mathematical models increased by 79%.[1] In addition to the emphasis on mathematical models, students also identified computational models more. This finding differed from the results previously reported by Carberry and McKenna (2014) after their studied intervention.[1] Significant differences between responses were found for Computer Models, as from pre- to post- decreased 20%; they proposed that this decrease was due to the emphasis and novelty of mathematical models in the presented activity.[1] The nature of the MATLAB course revolving around computer programming may have played a significant role in helping students identify computational models.

Upon completion of the CATIA course, students still tended to identify physical and virtual models more often. However, the number of students that identified mathematical and computational models increased slightly.

Gender Differences

The implementation of MEAs in a first-year engineering are one modeling intervention that has been proven successful for women to learn about modeling.[5] Based on the survey results, it appears that the MATLAB and CATIA courses had a positive impact on womens' awareness of model types, even more so than men in many instances.

Limitations

The data analysis for this study did not take many factors into consideration, such as different instructors and the impact of the design course. Also, the data analysis grouped the students together in the pre- and post- surveys and did not do a paired analysis – matching each student across their pre- and post- responses. There was also a limited evaluation of demographic factors due to a lack of diversity in the sample.

Conclusion

Engineers must be able to understand and create models in order to solve problems and do critical thinking in engineering. Students need foundational knowledge about basic modeling skills that will be effective in their courses, including the MATLAB and CATIA courses. The courses should ideally present an opportunity to help students solve problems logically and apply different modeling skills. This initial analysis demonstrates students' awareness of model types increased across the semester. Future work will further explore students' understanding of model relationships and applications.

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