Investigating First-Year Engineering Students' Understandings of Computer Simulations and Interactivity

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Conference Topic: Technology in Learning

INTRODUCTION

Nanotechnology is an educational topic that can ignite the imaginations of future scientists and engineers [1]. It is a cross-disciplinary field that engages engineers from all disciplinary backgrounds [2]. Not only is it an inspirational and encompassing educational topic, it is a field with many opportunities that is playing a significant part in future research directions. As such, the workforce demand and funding for the field of nanotechnology continues to increase [3]. While it is an intriguing educational topic and promising field of study, students have difficulties learning some fundamental nanotechnology concepts [4]. According to the National Centre for Learning and Teaching in Nanoscale Science and Engineering (NCLT) and the National Science Teachers Associations (NSTA), the use of computer simulations in nanotechnology is one tool for understanding the “big ideas” of nanotechnology education [5]. However, understanding what simulations are, how to use them, and how to develop them are difficult concepts for engineering students to grasp [6]. nanoHUB.org is an online community that promotes and supports the use of simulation tools for research and educational purposes [7].

Computer simulations are traditionally used in educational settings in one of two modes. More traditional lecture courses focus on teaching students what simulations are and how to build them through direct instruction. An example of this would be lectures based on a textbook that state types of simulations, types of variables in simulations, and give step-by-step directions to build the various types of simulations discussed. These approaches focus on factual knowledge rather than conceptual understanding. Computer simulations are also used in educational settings as well-developed tools for students to utilize to explore real objects, phenomena, and/or processes. This allows students to utilize well-developed simulations, but this approach typically does not focus on answering what the simulation tool is and how it is enabling the learners to explore the topic at hand.

This study investigates students’ conceptual understanding of simulation in a learning environment where engineering students are challenged to build their own simulations. This is a more interactive way of teaching students what simulations are and how to develop them. As the students develop their simulations, three interventions were used to advance students’ conceptual understanding of simulation: (1) in-class lectures about mathematical models and simulations, (2) formative feedback about project solutions from instructors, and (3) assessment of prototypical student work through a guided-instructional tool. This study focuses on the third intervention - students' responses to a series of prompts in the guided-instructional tool. The study is driven by the following research question: How do students' assess the presence of models and simulations and the level of interactivity in prototypical student-developed simulations?

1 LITERATURE REVIEW

1.1 Computational Simulations

Gould, Tobochnik, and Christian (2007) explain that the development of a computer simulation starts with the development of an idealized model of some physical system of interest [8]. A procedure or algorithm is then developed to implement the model in a computer system. The components that are selected to be explored and measured are then chosen to be the variables of the model. Simulations are differentiated throughout the authors' book by the simulation presentation mode, the level of interactivity, the types of interfaces in the simulation, and the types of models used to develop the simulation. The two simulation presentation modes are (1) the actual simulation with user choice of variable inputs and (2) an animation or visualization of a simulation run with default variables. The authors explain that the latter is not simply a video, but a type of animation that presents a captured segment of a simulation. The level of interactivity is defined by the degrees of freedom present in the simulation, which is determined by the number of model variables the user can manipulate. The types of interfaces and models used in the simulations present a level of complexity in simulation differentiation that is not addressed in this study.

1.2 Framework for Student-Developed Simulations

Rodgers, Diefes-Dux, and Madhavan (2014) proposed a framework for assessing and scaffolding student-developed simulations in an open-ended project [6]. The researchers explain that the three most important elements of a simulation are a well-developed mathematical model, interactivity, and visualization. The researchers developed the framework based on the analysis of 30 student teams' solutions to a design problem. The problem challenged teams to create Graphical-User Interfaces (GUIs) that teach their peers about nanotechnology through simulations. The resulting framework has four levels: (1) Basic Interaction, (2) Black-box Model, (3) Animation of a Simulation, and (4) Simulation.

Level 1: Basic Interaction refers to presence of any GUI components (e.g. buttons, editable text boxes, menus) that provide user interaction but do not provide interaction with a mathematical model. Level 2: Black-box Model requires some underlying mathematical model, but there is no model visual that explicates the relationship/s between the input/s and output/s. At this level, user inputs are fed into a hidden model to generate outputs, but no insight is provided into the model operating behind the simulation. The low model visibility fulfils the definition of black-box. Level 3: Animation of a Simulation requires a visual presentation of a model, but users can only play the simulation with default settings; there are no input variables that the user can set. This level has a higher level of model visibility than Level 2 and fulfils the definition of glass-box, but provides no user choice for exploring the model. Level 4: Simulation enables the user to change input variables and explore the nature of the mathematical model behind the simulation through appropriate visualization. This level is a glass-box approach with user choice.

2 METHODS

2.1 Setting and Participants

Purdue University has a First-Year Engineering (FYE) Programme, which all incoming engineers must complete to continue into their intended field of study. As part of this programme, students must complete a two-semester required introduction to engineering course sequence. Both courses begin with a project in which students learn about mathematical modelling and how to create a model based on data and problem context [9]. The second major project completed in each course is a design project. The design projects are completed through a series of milestones with specific deliverables [10].

In the second course, for three of the thirteen course sections, both the mathematical model and design project focus on nanotechnology. The Network for Computational Nanotechnology (NCN; nanoHUB.org) is the client for the students' design projects. The design project challenges student teams to make GUIs utilizing simulations to teach their peers about nanotechnology [10].

For the second milestone, students individually assessed three prototypical pieces of student work through a guided-instructional tool. The prototypical pieces of student work are de-identified, slightly modified samples created from previous student teams' submissions. The purpose of the tool is to have students critically evaluate a variety of GUIs (ranging from poor to high quality solutions) for the presences of models, simulations, and interactivity. The goal is to increase students' understanding of simulations and enable them to develop better simulations. In Spring 2014, 346 students (89 teams) developed nanotechnology-based simulations; 318 students completed this milestone.

2.2 Data Collection – Guided-Instructional Tool

The guided-instructional tool consists of three pieces of prototypical student work chosen to represent three of the four levels of simulation [6]. Example A represents Level 1: Basic Interaction. Example B represents Level 3: Animation of a Simulation. Example C represents Level 4: Simulation.

In Example A (*Fig. 1*), there are a series of clickable buttons on the left. Each button, when clicked, brings up text in the empty black space to explain the use of nanotechnology indicated on the button (e.g. photovoltaics, batteries). A schematic of the nanotechnology application also appears on the right. This example is classified as Basic Interaction because there is no mathematical model present.

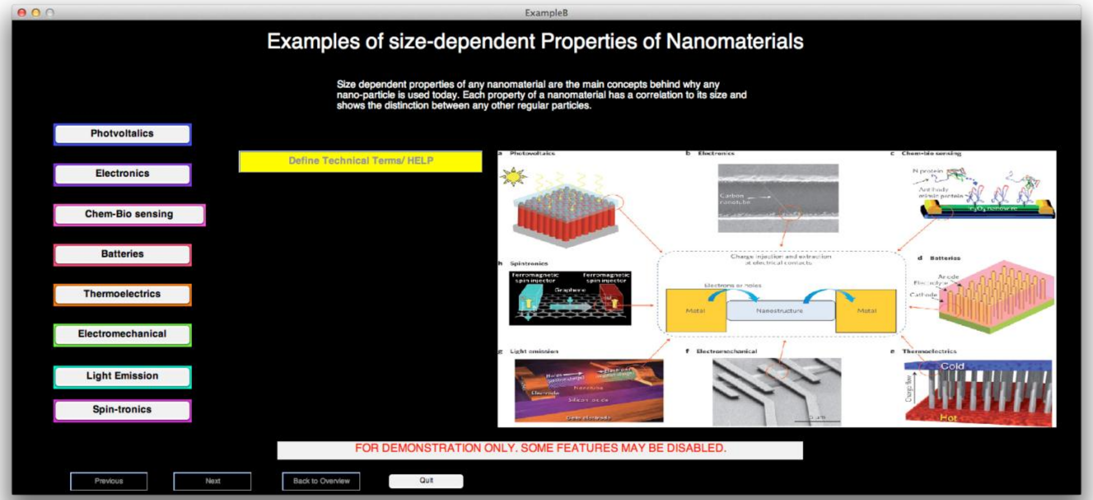

Fig. 1. Prototypical Student Work: Example A – *Level 1: Basic Interaction*

Example B (*Fig. 2*) consists of a play button that allows the user to watch an animation comparing energy absorption over time of solar panels with and without the application of nanotechnology. The screenshot shown is the comparison after 8 seconds has passed. This GUI fronts a mathematical model and allows the user to visualize the model. This GUI is an Animation of a Simulation because it plays an animation of the model for default parameters and does not provide for user choice for exploring the model; it, therefore, provides little user interactivity.

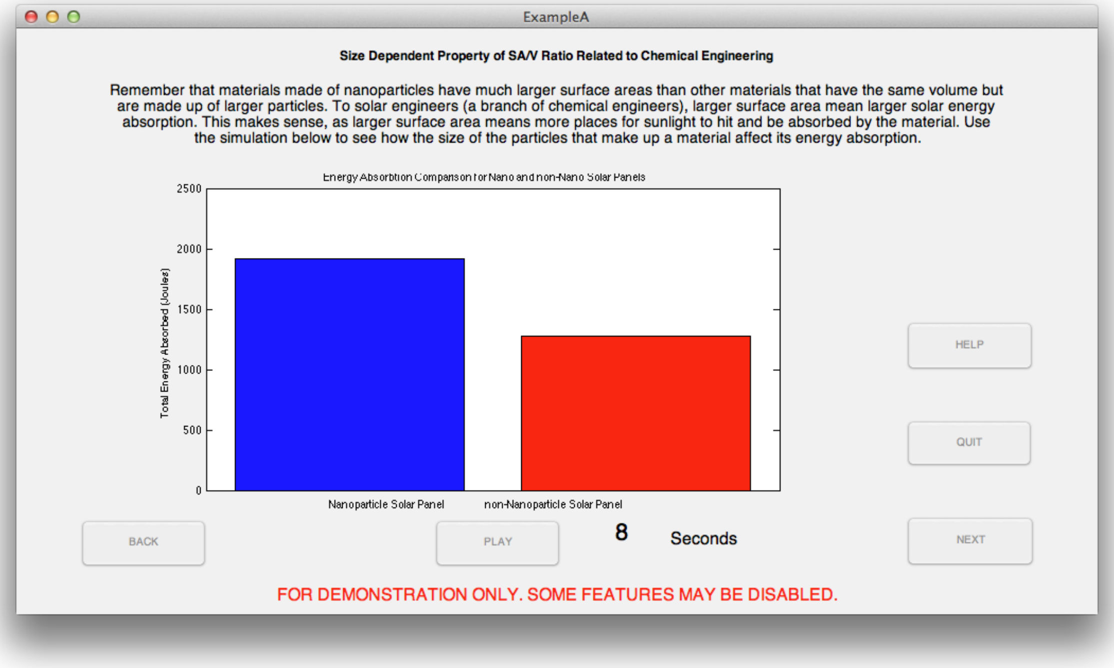

Fig. 2. Prototypical Student Work: Example B – *Level 3: Animation of a Simulation*

Example C (*Fig. 3*) consists of many input boxes on the left that allows the user to change the mass and charge of two objects to explore the big idea of forces and interactions. The plot on the left enables the user to visualize the effects of changing the input variables to the mathematical models. This example is a Simulation because it fronts mathematical models and provides user choice (interactivity) and visualization of the models.

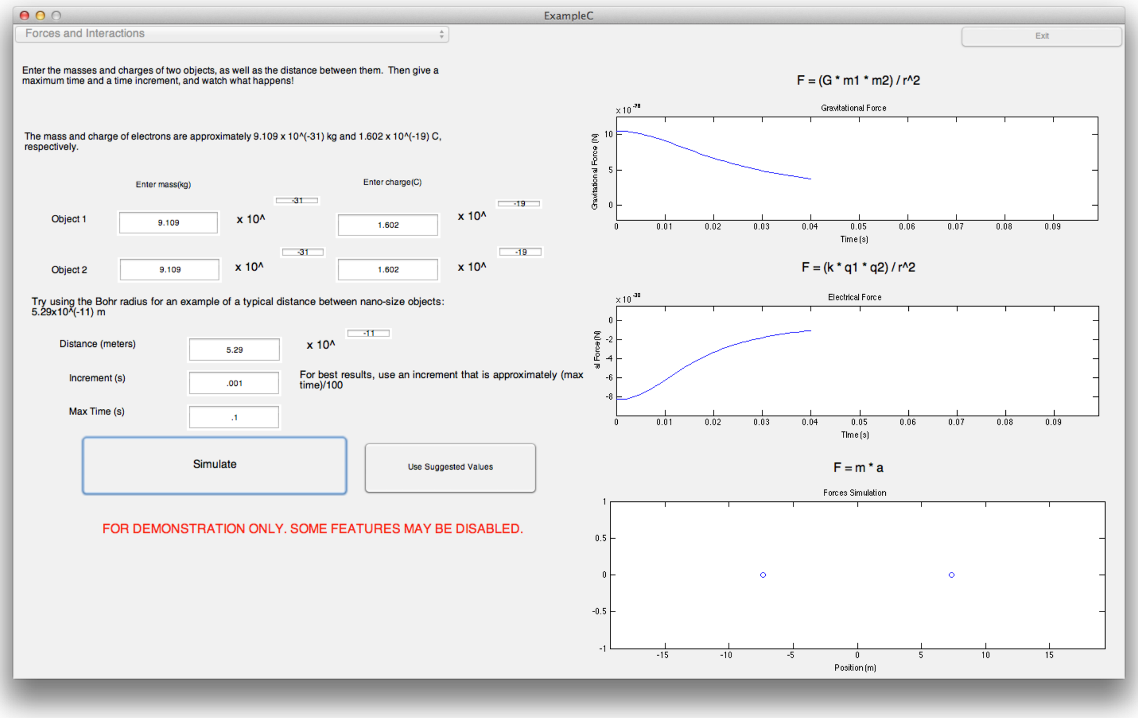

Fig. 3. Prototypical Student Work: Example C – *Level 4: Simulation*

The guided-instructional tool prompts the students to answer a series of questions about the three pieces of student prototypical work. For each example, the student must assess if there is a model only, a simulation only, both a model and simulation, or neither a model nor simulation present. The student must also assess the level of interactivity enabled. Students must select one of five levels of interactivity (Table 1) taken from the assessment tool used to evaluate students' work.. After responding to these two multiple-choice questions, the students are prompted to explain the answer they selected. After assessing each of these examples, the students must rank the three examples from best to worst on two aspects: (1) most use of simulations/models and (2) most interactive. The students are then required to reflect on how this task will impact their own design project. This final reflection question was not analysed for this study.

2.3 Data Analysis

The students' responses to all of the multiple-choice questions were quantitatively analysed. The rankings were also analysed to further understand the quantitative perspective of students' responses. A selection of open-ended responses about models and simulations were selected based on the quantitative analysis and then qualitatively analysed. The students' open-ended responses were analysed using open coding and axial coding to elicit patterns. These patterns were then categorized and quantified.

3 RESULTS

The results are presented in two sections: (1) interactivity and (2) models and simulations. The interactivity section consists of the quantitative results of students' multiple-choice and ranking responses. The models and simulations section consists of both quantitative results based on students' multiple-choice and ranking responses and qualitative results based on a few selected open-ended responses.

3.1 Interactivity

The 318 students' assessments of the interactivity of the three examples are shown in *Table 1*, with the most frequent response shown shaded in grey. There was a general consensus that Example B was not interactive and Example C was very interactive. This was further confirmed in the rankings: 87% of students ranked Example C as the most interactive (1st) and 75% of students ranked Example B as the least interactive (3rd). There seemed to be more confusion on the level of interactivity that Example A presented. Most students assessed Example A at a middle level of interactivity and 66% of students ranked Example A as the 2nd most interactive.

Table 1. Summary of students' responses about levels of interactivity

Level of Interactivity	**Example A: Level 1**	**Example B: Level 3**	**Example C: Level 4**
1-way communication only. No choice	18.9%	80.2%	0.6%
2-way communication is difficult to understand. High memory load.	10.4%	1.3%	6.6%
Limited 2-way communication, choice, and visual appeal. Some high memory load.	39.9%	13.8%	10.4%
2-way communication. Some user choice. Visually appealing. Infrequent high memory load.	20.4%	3.5%	27.0%
Meaningful 2-way communication and user choice. Visually attractive. Minimized memory load.	10.4%	1.3%	55.3%

3.2 Models and Simulations

The 318 students' responses to the multiple-choice question about the presence of models and simulations are shown in the charts in *Fig. 4*. Students generally agreed that Example A consisted of a model only – not a simulation (65%). Students had the most discrepancies in their responses about Example B. The students seemed to agree that there was something in this GUI, either a model

(26%), a simulation (36%), or both (35%), but they were not sure what. The students had the greatest agreement about Example C; the majority of the students (80%) reported that this GUI consisted of both simulation(s) and model(s). Some students (19%) reported that the GUI only had a simulation.

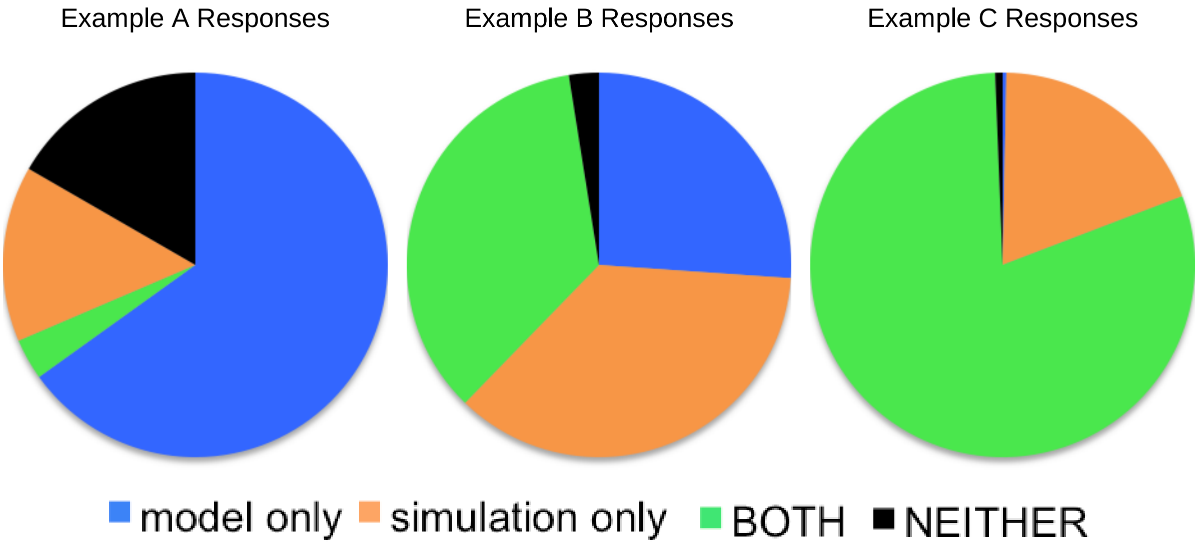

Fig. 4. Pie Charts of Students' Responses about Model(s) and Simulation(s)

The majority of students (85%) ranked Example C as the best representation of models and simulations (1st). The students did not have consensus on which example ranked second and third: 49% of students ranked Example B as second best and 48% per cent of students ranked it as third; 40% of students ranked Example A as second best and 47% ranked it as third.

The majority of students (207 out of 318) determined that Example A had a model present. This is an interesting response because there was not a mathematical model present in this GUI, so the students' explanations were further analysed. Out of the 207 students' responses, seven students only explained why it was not a simulation instead of why it is a model, one student responded that it was not a model after selecting it was a model in the multiple choice, and four students gave responses that could not be coded as they were off topic or did not focus on the question.

Based on the remaining 195 students' responses, the students explained that there was a model present because of the picture on the right, the buttons, the definitions, the resizing of the content, and/or the content focus. Most of the students discussed a couple of these ideas as meaning this GUI had a model. The most frequently (153 students – 79%) mentioned reason for considering this GUI to have a model was something related to the picture, chart, figure, or graph on the right side of the GUI. Some of the students referred to this as a physical model, graphical model, visual model, picture model, conceptual model, or model diagram. The second most (52% of the students) mentioned reason this GUI has a model referred to the definitions, information, or descriptions presented. Some of the students (31%) discussed the buttons on or user control of the GUI. Some of the students (39%) discussed the idea of nanotechnology making it a model, and 17 per cent of these students mentioned size-dependent properties specifically. A small group of students (6%) explained that the scaling/sizing of the content discussed (i.e. the pictures of nanoscale things were scaled up to make them visible on the macro scale) made it a model.

The students' responses about Example A, B, and C only having simulations are intriguing because all simulations are based on models. These student responses (n = 186) stated that the examples were only simulations and did not have models. The orange area in each of the pie charts (Fig. 4) represents this type of response. Out of the 186 open-ended responses about why the examples did not contain a model, five students changed their mind to restate that there actually was a model and nine students did not focus on the given question. Some students (10%) answered the question by simply stating that there just wasn't a model. Some students (13%) also stated that the example did not have a model and focused on the presence of a simulation. The remaining 129 students discussed various reasons why they felt there was not a model present in the respective example.

The most common response (63 students, 49%) was that there was no model present because there wasn't a physical model or visual representation of an object. One student explained their perspective of why a model was not present in Example B, "To me, a model is a physical representation of a physical object which are made to look like the actual physical object. This GUI only has graphs which are not made to look like objects in the real world." Another student explained their perspective of why Example C was not a model with a similar focus on the need for some visual of the observed object/s. The student wrote, "The GUI simulated their topic through the use of graphs, but they had no concrete example such as a picture or 3D shape of what they wanted to present."

Some of the other primary concepts that students focused on for why there wasn't a model present in the examples that they felt only had a simulation discussed in the students' responses were: it only had graphs (24%), the GUI needed more information (12%), there was no interaction (12%), it did not show how the object/concept "works" (10%), it was dynamic and models need to be static (9%), and it did not represent something from the real world (8%).

Students' responses included some comments that reveal their confusion about the relationship between models and simulations. One student explained that Example B was a simulation, but not a model. They wrote, "The bar graphs are visible changing. I consider moving images to be simulations more than models. Although it's such a boring and lifeless simulation that it very well may be a model." This is an example that shows a student's understanding that things can be models or simulations, but they are not both; rather than the true nature that simulations are based on models. Another student stated, "The simulation may be a model but I wasn't entirely sure if it counts as one due to it being a simulation." This again shows a student's confusion with the concept of something being solely one or the other versus potentially being both.

4 DISCUSSION

Based on these findings, first-year engineering students are fairly able to assess interactivity. Interactivity is a very important element of simulation. One aspect of interactivity that students may not understand is the difference between Basic Interaction interactivity (e.g. clicking buttons) and Simulation interactivity (i.e. variable inputs that enable meaningful user exploration of a model). This is a concept that should be further investigated in the future.

Two other important elements of simulation are the presence of a mathematical model and visualization of this model. Students struggled to understand when a model was present. Also many students seemed to think that simulations can exist without models and in some instance even think this is a requirement (i.e. models and simulations cannot coexist). Students' understanding of the relationship between models and simulations needs to be addressed more through classroom instruction and requires further investigation.

Some of the students' struggles with the presence of models may have been attributed to the language in the guided-instruction tool and the schematic shown in Example A. To enable better assessment of the students' understandings in the future, the tool should be revised. Instead of asking students about the presence of a model, it should ask about the presence of a mathematical model to specify the type of model required for a simulation. Example A is a good example to use to help students differentiate between a schematic or physical model and a mathematical model. It is also clear that the distinction between types of models and their purposes needs to be addressed through classroom instruction.

The difference between a mathematical model being present and the model being visually represented ("making it a simulation") should be better demonstrated in this tool. This can be done by having students assess a fourth example that represents a Level 2: Black-box Model [6].

5 CONCLUSIONS

The guided-instructional tool used in this study presents a method to assess students understanding of models and simulations. Analysis of students' responses to the tool prompts revealed confusion about what a model is and whether or not a simulation can exist without a model. The tool should be further revised based on this research to incorporate an example of a Level 2: Black-box Model solution and specifically ask students to assess GUIs for the presences of mathematical model(s), rather than models more generally. One way of assessing the scaffolding power of the tool is to compare the percentage of students' projects that contain a Level 4: Simulation in Spring 2013 (no tool implementation) and Spring 2014 (tool implementation). The presence of more and better simulations in Spring 2014 students' projects could indicate that the tool does help students' understandings of models and simulations.

6 ACKNOWLEDGMENTS

This work was made possible by a grant from the National Science Foundation (NSF EEC 1227110; NSF EEC 0956819). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

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