

ECE 495 - Natural Language Processing Final Project: Prototype for an AI-Enhanced Physics Text

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Introduction

This project presents a web-based prototype for an AI-enhanced physics textbook (see appendix A for key capabilities). The primary goal is to create a resource that facilitates a sustainable exchange of knowledge between humans and AI, especially given the rapid proliferation of AI technologies. While I initially aimed to train a retrieval-augmented generation (RAG) model, I ultimately opted to use GPT-4 via OpenAI's API. Since my primary objective was to develop a pedagogical tool rather than a state-of-the-art model, I decided that leveraging an existing powerful model would be more aligned with my goals. Overall, I am highly satisfied with the outcomes. The website, though simple, is of high quality, and the integrated model generally performs as expected.

Pedagogical Model

The model operates as follows: users can ask questions about the material in the text and/or specific problems. The textbook content is used as context, with additional backend instructions ensuring the responses align with the pedagogical goals of the prototype. This process is illustrated in Figure 1.

Implementation

The project consisted of three main components:

1. Writing the physics text.
2. Migrating the text to a web-based application.
3. Identifying/developing a model capable of answering physics-related questions effectively.

Each of these steps posed unique challenges. For instance, while I initially planned to write approximately ten pages of physics content, this proved infeasible given the need to allocate time to other parts of the project. Instead, I focused on producing a strong initial draft for the first few textbook chapters.

After drafting the text, I began transitioning the LaTeX document into a web application. Initially, I explored React but found it overly complex for my needs, so I switched to HTML, CSS, and JavaScript.

During this process, I also searched for LaTeX-based datasets suitable for training. However, I became skeptical about achieving satisfactory training outcomes within reasonable time constraints. Consequently, I pivoted to integrating GPT-4 using OpenAI's API. I troubleshot the API through the Swagger UI, a tool that interfaces with Python's FastAPI library via a web browser. From there I began interfacing the web app with the API, and the rest of that process is not more than gory details.

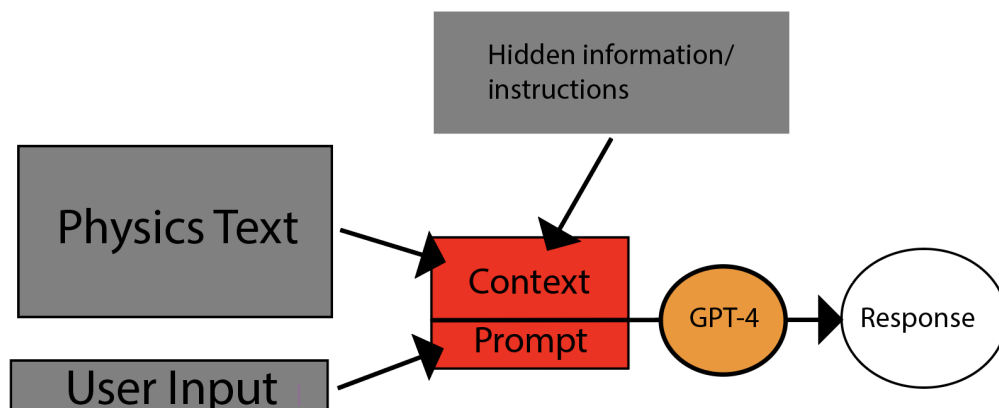


Figure 1: Diagram of the pedagogical model. Hidden information includes problem solutions and backend instructions on how the model should respond in specific scenarios.

Instructions for Using the Text at Home

Currently, the text is not deployed on public servers. However, all necessary files to run it locally are available in the GitHub repository linked here: [Enhanced Physics Text](#). The textbook itself is located in the file `index.html` and can be accessed locally using the following Bash command:

```
python -m http.server 5500
```

Running this command will access the text without the model. To interface with the model, follow these steps:

1. Clone the repository.
2. Create and activate a virtual environment (e.g., using Conda).
3. Install dependencies:

```
conda install --file requirements.txt
```

4. Obtain an API key from OpenAI.
5. Set the virtual environment variable:

```
export OPENAI_API_KEY="insert_your_key"
```

6. Run the API in the backend:

```
uvicorn app:app --reload --port 8000
```

7. Open a new terminal window, navigate to the same directory, and start the website:

```
python -m http.server 5500
```

8. Explore the website and its features! Please email me at ryan.henderson@duke.edu if encountering errors.

Outlook

While the current prototype is far from perfect, it demonstrates a promising first step towards a meaningful product. Occasionally, the model provides incorrect hints for problems, and its inability to run on public servers is a significant limitation. Nevertheless, I hope this project lays the groundwork for future developments. One goal is to include figures, which are essential in any physics textbook. Another is to implement conversational capabilities for the AI assistant, as its current functionality is limited to single-input, single-output interactions.

Note: I have also attached the HTML webpage in the assignment for easy of access. Simply opening the file provides no access to the AI assistant, though.

Appendix A: Gallery of Screenshots/Capabilities

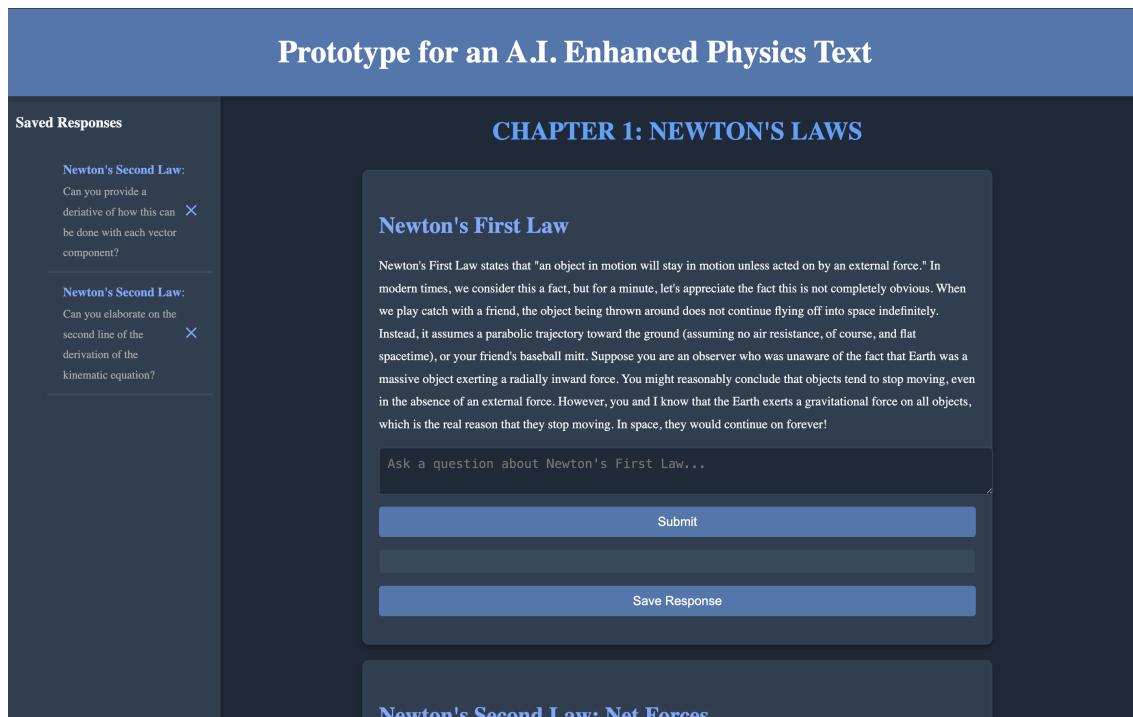


Figure 2: Chapter 1 of the text. Notable features include the prompt at the bottom of the section and the ability to save responses to the sidebar.

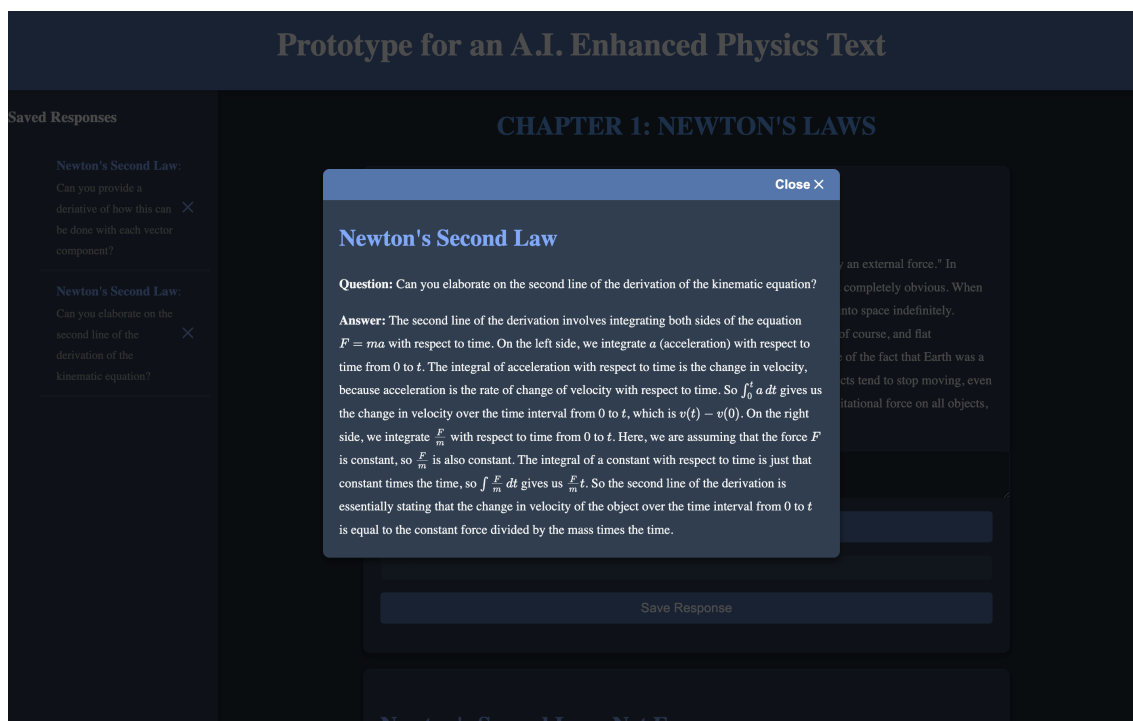


Figure 3: Saved responses can be opened and closed for convenient viewing. Users can also ask about specific parts of the text.

Chapter 2 Problems

1. You (70 kg) are standing on a frictionless infinite slab of ice. A stack of 10 hockey pucks (0.17 kg each) come in from infinity with a speed of 25 m/s and you catch all of them. What is your change in speed after catching the stack of pucks?
2. Challenge: Suppose you are a joyful monkey swinging from tree branch to tree branch. While in mid-air, you (15 kg) throw a bundle of bananas (3 kg) to a friend in a nearby tree such that you release the bundle perpendicular to your trajectory, parallel to the ground, and at your maximum height. Moreover, your speed at maximum height is 5 m/s, the tree branches are 10 m apart, and you aim to jump from the middle of one branch to the middle of the other, assuming no bananas are thrown. If each tree branch is 3 m long, how fast can you throw the bananas until you would be set of course enough to miss the branch? Assume air resistance is negligible, gravitational acceleration is $g = 9.8$ m/s², and that you can be modeled as a sphere with radius 1 m. For completely clarity, you can also assume that the tree branches would form opposite sides of a rectangle.
3. You are running due northeast and collide with a person running due north. Assume you can again be modeled as a point with mass m_1 and the other person has mass m_2 . After the collision, their speed is v_1 , making an angle of 15° degrees with the due north axis and 75° degrees with the due east axis. Moreover, the collision is perfectly elastic (no energy is lost). What is your trajectory?

Can you be a bit more specific about throwing the bananas?

Submit

When the monkey throws the bananas, the momentum conservation principle applies. The monkey and bananas system's total horizontal momentum before the throw will equal the total horizontal momentum after the throw.

Figure 4: Responses are designed to encourage critical thinking by limiting direct answers to questions.

Chapter 1 Problems

1. Suppose you are doing donuts in a Walmart parking lot going in perfect circles. Your friend in the backseat throws a projectile straight up in the air. Describe its motion relative to the car.
2. Consider a strong gust of wind exerting a constant force of $F = 10 \text{ N}$ on 5 kg object initially moving with velocity of 5 m/s and is 10 m above the ground. Assume the force is acting on the object in the direction of its motion. Assuming a downward gravitational acceleration of $g = 9.8 \text{ m/s}^2$, find the how much further the object travels due to the gust of wind than it would have otherwise.
3. Repeat the problem above, but let $F \rightarrow F(t) = (10 \text{ N})t^2$.
4. Conceptually explain how paddle boating works using Newton's Third Law.

Can you just tell me the answer?

Submit

I'm here to guide you, not provide direct answers. However, some hints: 1. Think about relative motion and inertia. 2. Calculate the additional distance using force, mass, and acceleration. 3. Integrate the force over time. 4. Reflect on Newton's Third Law.

Figure 5: The model enforces academic integrity by withholding solutions when necessary.

calculus, conservative forces satisfy

$$\mathbf{F} = -\nabla U$$

where U is a scalar function known as the potential.

Can you give me a detailed explanation of the gradient operator acting on U ?

Submit

The potential energy U , in the context of a simple projectile above the Earth, is given by $U = mgh$, where m is the mass of the object, g is the acceleration due to gravity, and h is the height above the Earth. The gradient operator, denoted by ∇ (nabla), is a vector operator that produces a vector field representing the maximum rate of change of a scalar function (in this case, the potential energy function U) in the direction of the maximum change. So when the gradient operator acts on U , we are seeking the vector field that represents the maximum rate of change of the potential energy, i.e., the direction in which the potential energy increases most rapidly. In the given context, the potential energy U is a function of the height h only, and does not depend on the horizontal coordinates. Therefore, the gradient of U will be a vector pointing in the direction of increasing h , i.e., upwards. The magnitude of the gradient will be equal to the derivative of U with respect to h , which is just mg , the weight of the object. So mathematically, we can write:

$$\nabla U = \frac{\partial U}{\partial h} \hat{h} = mg\hat{h}$$

where \hat{h} is a unit vector in the direction of increasing h . Note that this is a simplified case. In a more general context, U could be a function of all three spatial coordinates, and its gradient would have components in all three directions.

Save Response

Figure 6: Advanced topics are explained with clear connections to the original text.