Touching Nano: A New Way to Teach Nanoscale Concepts

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1. Objective

Concepts related to nanoscale phenomena, such as Van der Waal's forces, can be difficult to teach due to their complexity. Existing visualizations often target a narrow audience of advanced academics, which limits their accessibility to higher education students. In this project, we provide an interactive virtual reality visualization of Van der Waal's forces that is accessible and comprehensive to a wider audience, including K-12 students. The VR element of this project allows for embodied learning, as users can physically interact with the particles in real time and viscerally feel forces changing with customized haptic feedback. We developed this VR experience in Unity with the Unity XR Interaction Toolkit to be used with the Oculus Quest 2. The effectiveness of this experience in teaching the concepts of nanoscale phenomena will be evaluated through a survey comparing the user's prior knowledge of Van der Waal's forces before experiencing the simulation to their level of comfort with the concepts afterwards.

2. Motivation

Nanoscale phenomena involve structures with a length scale of 1 – 100 nanometers (1 nm = 1 e-9 m). Since these phenomena are so small, it is incredibly difficult and expensive to perform educational experiments to show them happening in real-time. Due to this, there are many visual representations, diagrams and simulations that have been created to demonstrate nanoscale phenomena for educational purposes. However, these visual representations are often difficult to understand and assume the viewer has certain prerequisite knowledge. This becomes especially problematic given that the concept of nanoscale phenomena is not typically taught until university, so most students are not equipped to understand these informational diagrams.

Virtual reality offers the opportunity to place students into settings or situations they never would be able to experience otherwise. Whether the setting is in a fallen city of the past, inside of a volcano or at the nanoscale, virtual reality allows students to safely experience the impossible.

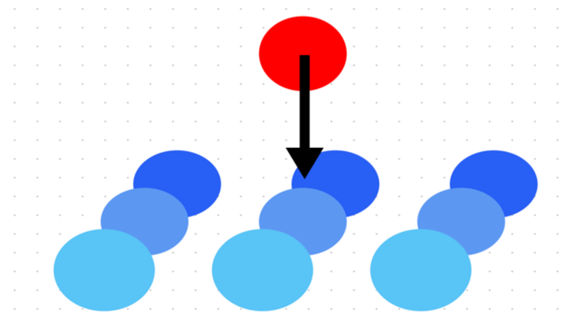

Figure 1: Original concept drawing for the simulation: the red atom is user controlled while all blue atoms enact separate forces resulting in haptic feedback for the user.

iXR Labs, one of many companies that specializes in the development of virtual reality educational experiences, says that "we retain 90% of what we experience as compared to 10% of what we read [1]." Embodied learning can be an extremely effective teaching tool when executed thoughtfully.

In 2012 researchers at Prairie View A&M University developed a product to teach nanoscale concepts in virtual reality. Their simulation allowed users to be fully immersed in a VR headset as a large projected screen simultaneously displayed the user's perspective in virtual reality to bystanders. The student in the headset was shown a variety of abstract nanoscale concepts simplified through clever simulations. The study planned to incorporate a haptic feedback device (PHANToM Omni haptic pen) but was not using it as of the paper's publishing date. The purpose of this haptic device was to allow the user to navigate the space, rather than experience forces [3].

Our final product will combine Unity's powerful physics engine with nanoscale concepts to give students a different way to visualize nanoscale phenomena. This virtual reality simulation paired with the haptic feedback of the Oculus Quest 2's controllers will provide a simplified visualization of Van der Waals forces and the interactions between atoms at the nanoscale.

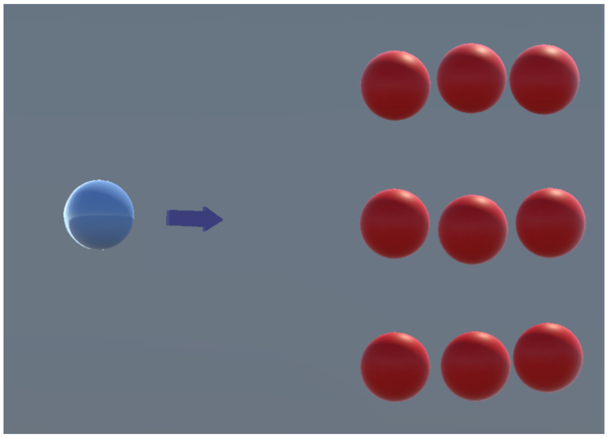

Figure 2: User particle and arrow (left) at its default distance from the particle wall (right).

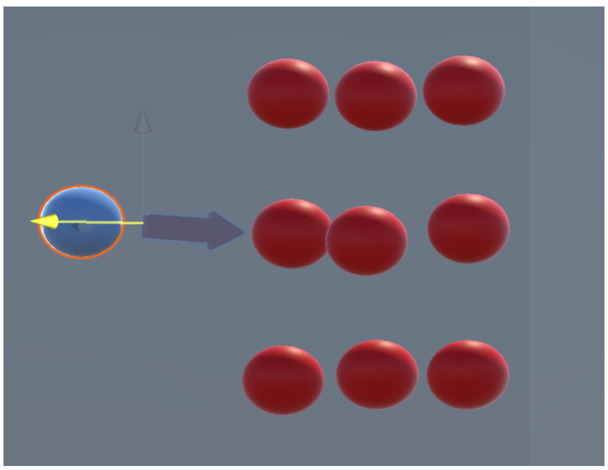

Figure 3: User particle and arrow (left) at a user-manipulated smaller distance from the particle wall (right). Note the difference in the arrow's size and color.

3. Approach

Using Unity Game Engine, a nanoscale simulation will be created with custom physics scripts derived from the calculation of Lennard-Jones potential energy, which will then be used to calculate the value of Van der Waal's force. The user will be able to grab an atom and attempt to forcibly move it toward a wall of other atoms. Due to the physics at work, the user will experience haptic feedback from the headset's controllers to indicate the strength of any opposing forces. This haptic feedback will be given in the form of vibration from the controllers, with stronger vibrations produced to indicate stronger opposing forces.

Additionally, the magnitude of the forces acting upon the user will be shown visually as the atoms become more active. Each atom will 'tremble' at a different speed and intensity according to the forces acting upon it. For example, if the user holds a particle close to one corner of the wall of particles, the speed each particle trembles at will be determined by its distance from the user's particle. In this example, the corner particle closest to the user's particle will tremble with the most intensity, while the particle on the opposite corner of the wall will tremble with the least intensity.

The changing forces will also be visually conveyed through an arrow that changes size and the direction of its pointing according to the magnitude of the forces the user's particle is experiencing, and where the forces are coming from. As the user brings their particle closer to the wall, they will notice as the arrow gradually grows and changes color.

4. Platform

We will be using Unity Game Engine to develop the simulation, and the Unity XR Toolkit to accelerate development. Testing will take place with an Oculus Quest 2. We have chosen not to proceed with a separate haptic feedback device for the time being and will be continuing development with the hands and controllers alone.

5. Development Process

The initial priority of this project was to fully understand the concepts it is meant to demonstrate. After days of research concerning Van der Waal's forces, London's Dispersion forces, Lennard Jones potential and other intermolecular interactions, we felt confident in our ability to properly incorporate the physics in our simulation.

Secondly, the Unity environment needed to be set up properly. Initially we had set our sights on using Microsoft's Mixed Reality Toolkit (MRTK) to aid in development processes. After much trial and error, it was determined that for the purposes of this project, integration with the MRTK was not needed. Instead, we reevaluated our development approach and pivoted to include the Oculus Integration SDK provided by Meta. This package was used to aid in the VR setup process and allowed us to change from developing for only the hands or controllers to allowing for both. However, development with this platform for controllers proved to be unproductive, and we finally switched to the widely used Unity XR Toolkit.

To provide a realistic visualization of the forces acting on the particles, we created a custom physics script that incorporates the real equations used to calculate intermolecular forces. The values for these equations are available to edit from within the Unity IDE, making it much easier for developers to test different values without having to edit the script each iteration. The result of these calculations is a vector that describes the direction and magnitude of the forces acting at any given moment on a particle. This value was then displayed on the wall to allow users to see the inverse relationship between distance between particles and the forces acting upon them.

The first iteration of this project placed the user in a blank room with two spheres, one red and one blue, within arm's reach. On the wall facing the user, we displayed the force vector for one of the particles. As the user interacted with the particles, the force on the wall would change as a reflection of the continuous calculation of the intermolecular forces.

After receiving user feedback from many other developers, we found that improving the user's experience was the most urgent adjustment. After all, we are trying to show the effects of highly advanced physics topics. As of the first iteration of the project, no explanations or explicit references of the actual concepts were included in the experience.

The second iteration of this project incorporated the Unity XR Toolkit to allow haptic feedback. Context for the lesson was provided on the wall behind the particle simulation. The text included a short explanation of Van der Waal's forces and Lennard Jones Potential, with added instructions to encourage the user's interaction with the particles. The force vector remained on the wall as a real-time measurement of the forces acting upon the particles.

In order to better convey the intermolecular forces, a 'trembling' script was created and applied to each particle in the scene. The intensity of the trembling is independently calculated for each particle and changes in real time as a response to changing forces. Additionally, an arrow was added to convey the magnitude of force acting upon the user's particle. As the user brings their particle closer to the wall of particles, the arrow expands and changes color. This effect was paired with the trembling script for a better visual effect.

Further development of this project will focus on creating a more immersive experience. Audio and visual cues will be added to aid in an explanation of the nanoscale phenomena. Further development of the UI is required, and the user experience will be of first importance as the development process continues. The inclusion of haptic feedback when using controllers will also be included in this development cycle.

6. Expert Evaluation

The first iteration of this project received mixed reviews. We were given feedback that the force values displayed on the wall were confusing and intimidating. We were provided many ideas as to how to visually explain the intermolecular forces. This feedback was not taken lightly, and as can be seen in Section 5, steps were taken to address these issues immediately.

During the second round of user feedback, we received many comments on the effectiveness of the visuals. Many developers noted an improvement in the overall quality and comprehensiveness of the lesson with the added arrow and trembling. The instructions and context on the wall were far more widely acknowledged as well, with most users pausing to read the wall before interacting with the particles.

Many suggestions for improvements were provided, such as the incorporation of a more robust physics script. The addition of a user interface menu to help streamline the experience was also suggested. These improvements will be added as a part of our next phase of development.

7. Future Plans

There are many plans in place for our next phase of development. Our first task will be to improve the accuracy of the physics simulation. Additionally, improvements to the haptic feedback and user interface are of the top priority. Beyond these tasks, general user experience improvements will be made to create a more streamlined experience.

Once initial development has completed, user testing will be performed to determine the effectiveness of our product in teaching nanoscale concepts. Users will be asked a series of questions concerning their knowledge and understanding of nanoscale phenomena before and after their virtual reality experience. Users will also be asked about their knowledge of virtual reality, the effectiveness of using virtual reality as an educational tool to teach nanoscale concepts, and their overall experience in the simulation. Users will be asked to provide a definition in their own words of Van der Waal's forces, and asked on a Likert Scale how confident they feel in their ability to explain the concepts by themself. The final question of the survey will be a free-response question asking for any additional feedback users may have on the experience. Other data collected during the survey will involve user demographics such as age, highest level of education completed, experience with physics concepts, whether they have ever taken a physics course, and how intimidating they find learning new physics concepts to be. Using this data, development will be revisited to address the feedback provided by the users on their experiences and improve on areas of weakness.

8. Results

Our experience has improved quite a bit since its initial iteration, but there is still much to be done before this project is ready to be experienced by the world. We hope to provide an accessible simulation to teach a not-so accessible concept. Never forgetting those who will benefit from this work, we will continue to improve our VR experience and explore new ways to teach.

References

[1] iXR Labs. *Engineering VR Labs* [Online]. Available: https://www.ixrlabs.com/engineering.php

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[3] Peng, X., & Isaac, B., & Wilkins, R. T. (2012, June), *Development of Nanoscale Virtual Reality Simulations for the Teaching of Nanotechnology*. Paper presented at 2012 ASEE Annual Conference & Exposition, San Antonio, Texas. 10.18260/1-2--21221