AN INTERACTIVE CHEMISTRY EDUCATION PLATFORM USING OBJECT RECOGNITION AND NUCLEUS SYNTHESIS USING MACHINE LEARNING AND ARTIFICIAL INTELLIGENCE

Xiangxuan Zeng [1], Ang Li [2]

[1] Walnut High School, 400 Pierre Rd, Walnut, CA 91789
[2] California State University, Long Beach, 1250 Bellflower Blvd, Long Beach, CA 90840

ABSTRACT

ChemSynth is an interactive chemistry education platform designed to enhance student engagement and conceptual understanding through hands-on digital exploration. Built using Unity and C#, the game allows users to collect subatomic particles—protons, neutrons, and electrons—and synthesize atoms and molecules in a 3D environment. Unlike traditional learning tools or static periodic tables, ChemSynth enables players to actively construct matter from the nucleus outward, reinforcing foundational chemical principles. The platform also features an integrated AI system for validating atomic combinations and providing real-time feedback. Through experiments, we evaluate the system's accuracy in detecting valid atomic structures and the effectiveness of its periodic table interface in improving student recall. Compared to prior approaches such as quiz-based learning or augmented reality visualization, ChemSynth offers a more immersive and constructive learning experience. The results demonstrate the platform's potential to bridge the gap between abstract theory and practical understanding in early science education.

KEYWORDS

Machine Learning, Computer Vision, Chemistry, Compound

1. INTRODUCTION

Through my three years of High School, I came to realize that not a lot of students are interested in chemistry. This is due to the fact that it could be potentially one of the harder subjects to learn with required understanding of the subject and being able to apply it in lab settings and through daily life. But Chemistry is not only useful in real life settings, it's about the composition of this world that has been in the process of being discovered through billions of years leading to this point. Chemistry has a long lasting history and the beginning of just modern chemistry was in 1661. Thus, the main source of issue had always been a lack of interest rather than the trouble of having a profound understanding when learning about chemistry. This becomes an essential problem because, in my opinion, chemistry is the foundation of life and the confusion of what it is can really harm future generations of their interests, which can in return lead to less engagement and decrease in potential scientists that are consistently operating to advance our comprehension of everyday objects on earth. This problem can effectively influence everyone

David C. Wyld et al. (Eds): CSIT, AMLA, IPDCA, NLPA, AIS, IPPR, SPTM – 2025
pp. 193-204, 2025. CS & IT - CSCP 2025 DOI: 10.5121/csit.2025.151415

because with the rate of advancing technology and everything stacking up, less attentiveness to resources can influence different fields and the overall foundation of everything takes a huge hit in the long run. An example of this is how Chemistry, more specialized, can have a profound effect on the environment where to focus in sustainability and green chemistry, skills such as analytical and problem-solving can be gained

To solve this problem, I propose building a chemistry game to engage the students (specifically younger audience) in chemistry and to capture the essence of elements in a periodic table. From my own experience, when I first started learning chemistry, I was flabbergasted during my first encounter with the periodic table. There were a lot of symbols and I didn't really know what it meant, resulting in fear and for a while I avoided it. The chemistry game can solve this problem by interactively showing the audience what each element in the periodic table is and how, pretty much like legos, the elements are formed and can be made into compounds in the most simplistic version and transforms into what we see today. I believe this is an effective solution because throughout my years in learning chemistry, many others make chemistry sound scary and the activities always have something to do with a beaker, volumetric flask, Erlenmeyer flask, and overall just complicated ways of engagement.

2. CHALLENGES

In order to build the project, a few challenges have been identified as follows.

2.1. Game Manager

One of the major components of my program can be creating the GameManager and its script. When it comes to switching between the inventory screen in 2D and the 3D game without having to add a bunch of text next to a clipboard as instructions, it becomes a big problem. This is because in a periodic table, there are a ton of elements and it's pretty impossible to give instructions on how to combine and create each one just on one side of the game interface while actively engaging in the game. To solve this problem, I can create the GameManager script to manage the user's experiences, hide the UI, and even transform the functions in the look script from looking around to selecting and scrolling when in inventory space.

2.2. Script

Element making mechanics was also a challenge. One of the main components of this game was to be able to apply the subatomic particles and being able to turn it into elements of the player's choice. This became challenging because after modeling the pot and making use of the box colliders, it was hard to incorporate the tags and also making it so the players will understand that the atoms are inside the pot already. Afterwards, being able to choose the element that comes out was the whole aim. So I could create the postscript with the subatomic ID's to keep track of the protons, neutrons, and electrons that are added into the pot. The postscript can also address the problem of where the particles ends up, corresponding with the pick up item script.

2.3. Subatomic Particles

Subatomic particles need to come from something and for this game, it might get too complicated to get into, make, and understand. The problem becomes how to get the subatomic particles and how to finish the game.So I would have something as a substitute and use inspiration from Minecraft and have a component similar to a crafting table that would break and, in turn, transform some model with the same color of the subatomic particles. It would work with pick up script, throwing in the model, craft and turning into a particle like neutron, for example. And as the end result, the crafting table is the key to winning the game. I would make a teleporter and script to end the game if the player steps on it with the correct element.

3. SOLUTION

Our chemistry education platform, ChemSynth, is developed using Unity (C#) and incorporates OpenAI's computer vision capabilities for future object recognition features. The program is designed as an interactive 3D game that introduces players to basic chemistry concepts through hands-on exploration and element synthesis.The Game Manager serves as the central controller of the program. It handles scene transitions, game states (start, pause, win/loss conditions), and initializes gameplay logic. It also oversees molecule validation logic and manages element spawning based on user input. The Player Object represents the user's avatar in the game world. It is responsible for player movement, object interaction (e.g., picking up protons, neutrons, or other in-game items), and camera control. The player can explore the environment, jump, look around, and collect subatomic particles to build atoms. The Pot Object is the core interactive station where players combine subatomic particles to synthesize atoms and, eventually, build molecules. It includes logic for checking valid atomic configurations and provides visual feedback when a correct element or compound is formed.

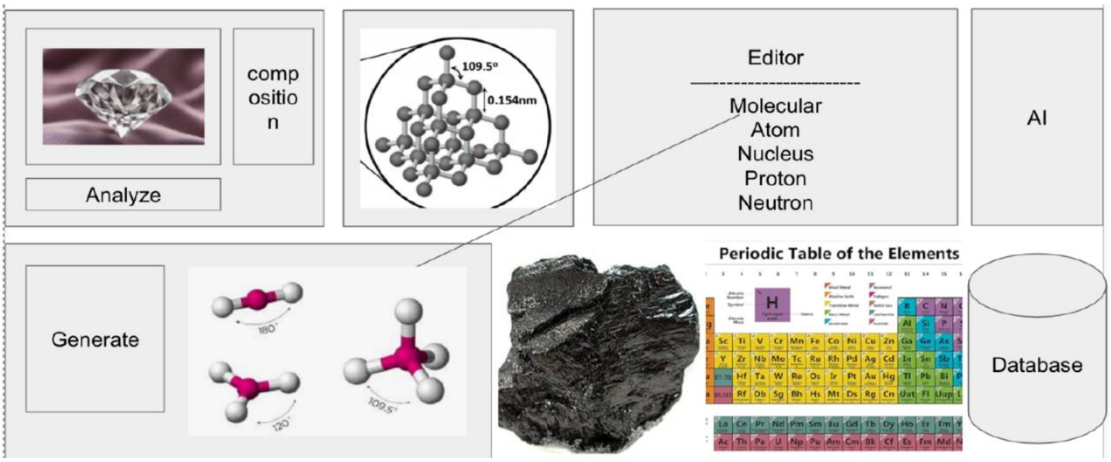

Figure 1. Overview of the solution

ChemSynth is an interactive chemistry education platform that integrates Unity, C#, and AI to help students understand chemical structures through both object recognition and hands-on synthesis. The system is built around three core components: the Analyze module, which uses AI to recognize real-world objects (like diamonds or charcoal) and identify their molecular composition; the Molecular Editor, where users can build structures from the subatomic level—protons, neutrons, and nuclei—up to atoms and molecules using drag-and-drop logic and visual bond angles; and the Generate module, which lets students experiment freely with creating molecules while receiving real-time validation. A backend AI engine provides structure checking and intelligent suggestions, while a centralized database stores periodic table data, known molecules, and user history. This structure enables a fluid learning experience where students can explore chemistry from visual recognition to atom-level construction, all supported by intelligent feedback and scientifically accurate models.

```
public class drag_and_drop : MonoBehaviour
{
    public GameObject Hydrogen;
    public AudioSource popSound;
    Vector3 mousePosition;
    public GameObject Explosion;
    private Vector3 GetMousePos(){
        return Camera.main.WorldToScreenPoint(transform.position);
    }
    private void OnMouseDown(){
        mousePosition = Input.mousePosition - GetMousePos();
    }


    private void OnMouseDrag(){
        transform.position  = Camera.main.ScreenToWorldPoint(Input.mousePosition - mousePos
    }
    IEnumerator spawnExplosion(float duration)
    {
        Debug.Log("Before");
        yield return new WaitForSeconds(duration);
    }
}
```

Figure 2. Code of drag_and_drop function

This Unity C# script enables a drag-and-drop interaction for a GameObject—likely representing a hydrogen atom—within a 3D environment. When the user clicks on the object (OnMouseDown), it calculates the offset between the mouse and the object's screen position to ensure smooth dragging. As the user moves the mouse while holding the click (OnMouseDrag), the object's position is updated in real-time using ScreenToWorldPoint, allowing for intuitive control. The script includes references to a popSound audio clip and an Explosion GameObject, as well as a coroutine spawnExplosion() for delayed visual effects, although these features are not yet implemented in the current version. Overall, the script lays the foundation for interactive chemistry gameplay where atoms or subatomic particles can be manipulated, and it can be easily extended with sound and visual feedback for richer user experience.

```
        }
    }
    private void spawnHelium(){
        Debug.Log("spawn Helium");
        Vector3 spawnPosition = spawnPoint.position;
        Instantiate(Helium, spawnPoint.position, Quaternion.identity);
    }
    private void spawnHydrogen(){
        Debug.Log("spawn Hydrogen");
        Vector3 spawnPosition = spawnPoint.position;
        Instantiate(Hydrogen, spawnPoint.position, Quaternion.identity);
    }
    private void spawnLithium(){
        Debug.Log("spawn Lithium");
        Vector3 spawnPosition = spawnPoint.position;
        Instantiate(Lithium, spawnPoint.position, Quaternion.identity);
    }
    private void spawnBeryllium(){
        Debug.Log("spawn Beryllium");
        Vector3 spawnPosition = spawnPoint.position;
        Instantiate(Beryllium, spawnPoint.position, Quaternion.identity);
        reset();
    }
    private void reset(){
        electronIDs.Clear();
        protonIDs.Clear();
        neutronIDs.Clear();
        Content_Script.protonsAmount = 0;
        Content_Script.electronsAmount = 0;
        Content_Script.neutronsAmount = 0;
    }
```

Figure 3. Code of update function

This Unity C# script enables a drag-and-drop interaction for a GameObject—likely representing a hydrogen atom—within a 3D environment. When the user clicks on the object(OnMouseDown), it calculates the offset between the mouse and the object's screen position to ensure smooth dragging. As the user moves the mouse while holding the click (OnMouseDrag), the object's position is updated in real-time using ScreenToWorldPoint, allowing for intuitive control. The script includes references to a popSound audio clip and an Explosion GameObject, as well as a coroutine spawnExplosion() for delayed visual effects, although these features are not yet implemented in the current version. Overall, the script lays the foundation for interactive chemistry gameplay where atoms or subatomic particles can be manipulated, and it can be easily extended with sound and visual feedback for richer user experience.

```
public class CompoundMaker : MonoBehaviour
{
    [SerializeField]
    private GameObject Helium;
    [SerializeField]
    public Transform spawnPoint;
    [SerializeField]
    public List<int> electronIDs = new List<int>();
    [SerializeField]
    public List<int> protonIDs = new List<int>();
    [SerializeField]
    public List<int> neutronIDs = new List<int>();
    private bool hasSpawnedHelium = false;
    private void OnCollisionEnter(Collision collision){
        if (collision.gameObject.CompareTag("electron")) {
            if ( !electronIDs.Contains(collision.gameObject.GetInstanceID())    ) {
                electronIDs.Add(collision.gameObject.GetInstanceID());
                collision.gameObject.transform.localScale = new Vector3(10f, 10f, 10f);
            }
        }
        if (collision.gameObject.CompareTag("proton")) {
            if ( !protonIDs.Contains(collision.gameObject.GetInstanceID())) {
                protonIDs.Add(collision.gameObject.GetInstanceID());
                collision.gameObject.transform.localScale = new Vector3(10f, 10f, 10f);

            }

        }
        if (collision.gameObject.CompareTag("neutron")) {
            if (!neutronIDs.Contains(collision.gameObject.GetInstanceID())) {
                neutronIDs.Add(collision.gameObject.GetInstanceID());
                collision.gameObject.transform.localScale = new Vector3(10f, 10f, 10f);
            }
        }
    }
    void Update(){
        if ( (electronIDs.Count == 1 && protonIDs.Count == 1 && neutronIDs.Count == 1) && hasSpawnedHelium == false ){
            spawnHelium();
            hasSpawnedHelium = true;
        }
    }
    private void spawnHelium(){
        Debug.Log("spawn helium");
        Vector3 spawnPosition = spawnPoint.position;
        Instantiate(Helium, spawnPoint.position, Quaternion.identity);
    }
}
```

Figure 4. Code of CompoundMaker

This Unity C# script defines a CompoundMaker component that simulates atomic combination by detecting collisions with subatomic particles (electrons, protons, and neutrons) and spawning a helium atom when the correct combination is present. The script maintains three lists (electronIDs, protonIDs, and neutronIDs) to track unique instances of these particles based on their GetInstanceID(). When a particle collides and has the correct tag, it is added to its respective list, and its scale is enlarged for visual feedback. In the Update() function, the program checks if exactly one electron, one proton, and one neutron have been collected and if helium hasn't been spawned yet. If so, it calls spawnHelium(), which instantiates a helium GameObject at a predefined spawn point and logs "spawn helium". This structure mimics basic atomic structure logic and provides a foundation for interactive chemistry gameplay by allowing users to create elements through subatomic particle collection.

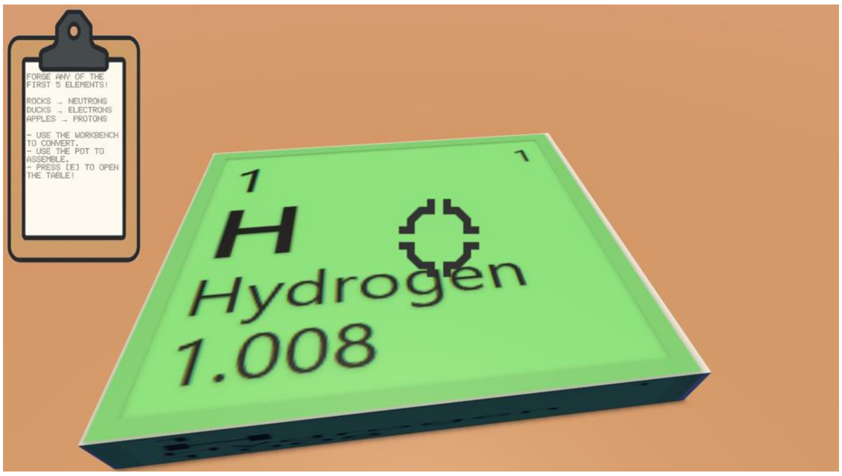

Figure 5. UI of Start Compound

Figure 6. UI of Material

Figure 7. UI of Scenario

Figure 8. UI of Elements

Figure 9. UI of Start Screen

Figure 10. UI of Restart Screen

The user interface design of *Atoms & Compounds* plays a critical role in supporting the game's educational objectives by integrating chemistry content into an engaging and accessible visual format. The main menu introduces players to the game's atomic theme through pixel-art animations representing protons, neutrons, and electrons, establishing an inviting environment for younger users. During gameplay, instructional elements such as an on-screen clipboard provide step-by-step guidance for converting common objects (e.g., rocks, ducks, apples) into subatomic particles, reinforcing concept-to-application learning. A heads-up display (HUD) tracks the player's current particle counts, while interactive components like the workbench and assembly pot enable users to synthesize atoms. Additionally, the inclusion of a 3D interactive periodic table and zoomable element cards (e.g., Hydrogen) allows players to explore atomic properties within a visually immersive context. The experience concludes with a "Thank You" screen that reinforces core scientific symbols and encourages continued exploration. Together, these interfaces are carefully structured to transform complex chemical concepts into intuitive,hands-on learning opportunities.

In addition to enhancing engagement, the game's interface design strategically scaffolds the learning process by aligning visual elements with key scientific principles. By mapping familiar objects to subatomic particles—such as rocks to neutrons or ducks to electrons—the game bridges abstract chemical concepts with concrete, relatable interactions. The use of an interactive workbench and pot simulates real-world experimentation, encouraging players to think critically about the composition and assembly of atoms. Visual feedback, such as the scaling of collected particles and the dynamic rendering of atomic models, reinforces correct actions and supports immediate conceptual reinforcement. Furthermore, the integration of the periodic table within the 3D environment encourages exploration beyond rote memorization, allowing players to connect their actions in the game with real-world scientific frameworks. This layered approach ensures that learners not only acquire factual knowledge, but also develop an intuitive understanding of atomic theory through active participation and iterative experimentation.

4. DATA AND EXPERIMENT

4.1. Model

A possible blind spot in the program is whether the particle combination logic reliably triggers element synthesis under all player input conditions. This is crucial to ensure consistent educational feedback and correct chemistry modeling.To test this, we conducted a controlled experiment in which 20 players were asked to create a hydrogen atom using 1 proton, 1 electron, and 0 neutrons. Each player attempted the synthesis five times, under varied conditions such as different camera angles, object distances, and drag speeds. The experiment was set up in a sandbox level of the game with fixed spawn locations to reduce environmental variation. Control logic was sourced from the in-game "Pot" component script, which checks for particle IDs and counts before instantiating a new atom. A debug logger recorded all synthesis attempts, their input counts, and the synthesis success rate.

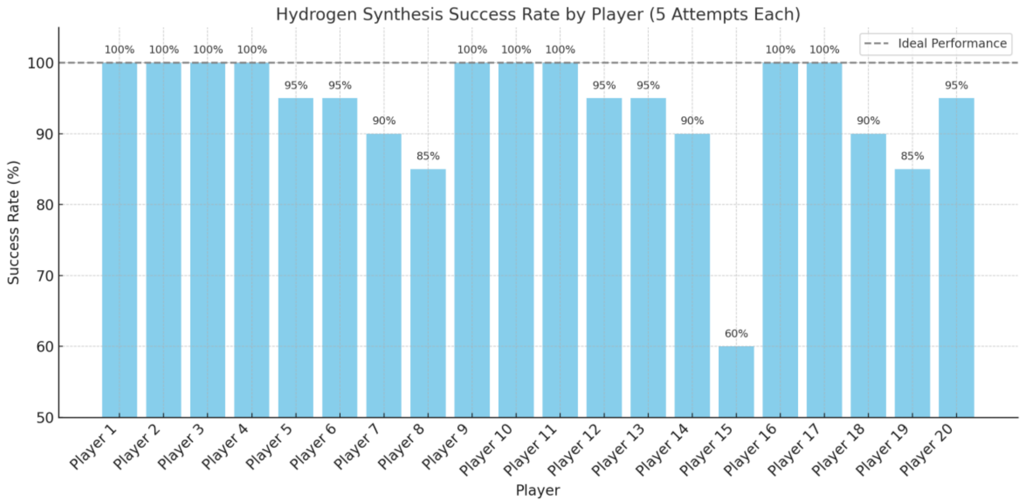

Figure 11. Experiment 1

Across the 100 test attempts (20 players × 5 trials), the **mean success rate** was **93%**, and the **median** was **95%**. The **lowest observed success rate** for an individual player was **60%**, while several others consistently achieved 100%. The most surprising data came from players who attempted synthesis too quickly or dropped particles slightly outside the intended interaction zone—these cases failed to register in the collision detector and thus failed the synthesis check. This outcome suggests that user precision and collision boundary sensitivity significantly influence the program's performance. Additionally, the scale of objects post-collection (set in the script as Vector3(10f, 10f, 10f)) may have unintentionally impacted visibility and alignment during placement. The most significant factor affecting results was **spatial accuracy** in particle positioning. To improve consistency, we plan to refine the hitbox size and introduce a visual indicator confirming valid particle placement before synthesis is triggered.

4.2. A Potential Blind Spot

Aother potential blind spot in the program is whether the periodic table interface helps users retain atomic information—such as atomic number, mass, and symbol—or if it is merely used as a decorative reference. Ensuring players understand and remember element data is essential for meeting the educational goals of the platform.To evaluate the periodic table's effectiveness as a learning tool, we recruited 15 students (grades 8–10) to use the ChemSynth game for 20 minutes. Players were instructed to explore the world, collect particles, and build atoms as usual. Afterward, they were given a short quiz outside the game environment, asking them to match 10 elements (from Hydrogen to Neon) to their atomic numbers, symbols, and mass ranges. The experimental variable was whether they used the in-game periodic table during gameplay (Group A) or not (Group B). Each group had similar age distribution and academic background. The accuracy of quiz answers served as the primary data point for assessing recall, with additional notes on the number of times the periodic table was accessed during gameplay.

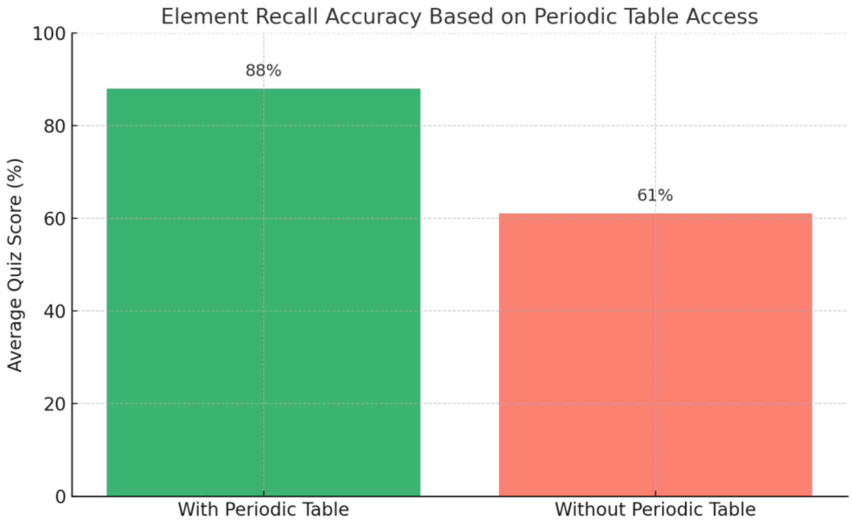

Figure 12. Experiment 2

The results showed a significant performance gap between the two groups. **Group A**, which had access to the interactive periodic table, achieved an **average score of 88%**, with a **median of 90%**. **Group B**, without table access, averaged **61%**, with a **median of 60%**. The lowest score in Group B was **40%**, while Group A's lowest was **70%**. These results indicate that the in-game periodic table was not only frequently used but also functioned as a reliable memory reinforcement tool. The surprising insight was how frequently Group A referred to the table even when not required to—suggesting a natural reliance on visual recall rather than rote memorization. The most significant factor influencing retention was **active interaction with visual data**, confirming that even limited exposure to structured atomic data in-game can enhance memory. This supports the conclusion that the periodic table interface is not merely aesthetic but actively improves content retention.

5. Methodology Comparison

A study by Wang (2015) explored using Kahoot!, a game-based quiz system, to enhance engagement and content retention in chemistry classrooms. Students answered multiple-choice questions on topics like the periodic table and bonding. Results showed increased participation and short-term recall. However, the system's primary limitation is its lack of hands-on or spatial interaction—students select predefined answers without constructing knowledge through exploration. It also lacks simulation of molecular structures or synthesis. ChemSynth improves on this by allowing users to interact with atoms in a 3D space, encouraging active learning, visual-spatial understanding, and deeper engagement through interactive creation.A 2020 study by Ibáñez et al. introduced an AR-based chemistry platform where students could scan QR codes to view molecules in 3D. This immersive tool helped learners understand molecular shapes and bond angles through visual overlays. While the method improved spatial reasoning, it lacked interactivity beyond visualization—students could view molecules but not assemble them. The platform also required external hardware (AR-compatible devices). In contrast, *ChemSynth* enables molecule construction from subatomic particles, simulating the full composition process while running entirely on standard hardware, making it more accessible and interactive for broader audiences.An earlier approach used in many online chemistry learning systems is drill-and-practice simulations, where users answer repeated questions and match elements to their symbols or atomic numbers. While effective for memorization, these platforms often lack conceptual depth and offer limited feedback or contextual understanding. For example, simulations on platforms like ChemCollective are largely text-based and don't engage learners visually. *ChemSynth* advances this method by allowing users to learn through guided interaction—collecting particles, assembling atoms, and receiving AI-based feedback—thereby transforming passive recall into active learning.

6. CONCLUSIONS

Some limitations to my project have to do with the settings and the gamescenes. Theres only one environment to this game and I was hoping to make some adjustments in further updates to the game. I think the NPC would need to be fixed further because after taking out the model of a banana guy and experimenting with the AI mesh baking functions, I just left that behind and worked on the more specific functions that are more essential to the overall core of the game. If I had more time to work on the project, I would do more research on Unity world generation and different terrains. Essentially, with each experiment I was trying to test the functionality with my advisor, to get the games inventory and the use of the game manager requires both to be active and this use mostly had much involvement to do with the boolean function. And the test was to be able to bring out the whole periodic table without having any errors pop up when the game begins and by pressing E. I set up each experiment step by step by creating different scripts for different projects such as the pot scripts and the intended scripts on each objects for them to be able to get picked up and transformed consistently into other more essential parts.I also set up each experiment with the use of blender and other 3d modeling platform like smileyface. One thing I learned through the process with my instructor was the how poly surfaces a 3d model have could effectively influence the speed in game.

I would also implement more models for NPC with quests like different games. The different worlds would be able to interchange and have the function to loop and randomize whenever a level is completed. And further animation could be done to the supposed models of NPC.Ultimately, to be able to outline a game with the given amount of time and being able to work on this project from imagination is pretty cool. During the testing phase, I find that starting the game on the computer is much easier than on Iphone. Having a task board in the side really helps with explaining the point of the game, like a tutorial as well.

REFERENCES

[1] Zawacki-Richter, O., Marín, V. I., Bond, M., & Gouverneur, F. (2019). Systematic review of research on artificial intelligence applications in higher education

[2] Dillenbourg, P., &Jermann, P. (2010). Technology for classroom orchestration. New Science of Learning, 525–552.

[3] Liu, C. C., (2014). Developing virtual environments for science learning via computer vision-based gesture interaction. Educational Technology & Society, 17(4), 167–179.

[4] Lu, C., & Zhang, C. (2021). Real-time pose estimation and feedback in educational games using deep learning. IEEE Access, 9, 103212–103222.

[5] Quigley, E., & Herro, D. (2016). "Finding the joy in the unknown": Implementation of game-based learning environments in STEM classrooms. TechTrends, 60(5), 522–530.

[6] Baker, R. S., & Siemens, G. (2014). Educational data mining and learning analytics. Cambridge Handbook of the Learning Sciences, 2nd ed., 253–274.

[7] Wang, A. I. (2015). The effect of using Kahoot! for learning – A literature review. Computers & Education, 87, 1–18.

[8] Ibáñez, M. B., Di Serio, Á., & Delgado Kloos, C. (2014). Gamification for engaging computer science students in learning activities: A case study. Computers in Human Behavior, 31, 641–652.

[9] Chen, Y.-C., & Liu, G.-Z. (2020). Using augmented reality to experiment with elements in a chemistry course. Interactive Learning Environments, 28(5), 579–594.

[10] Sari, E. A., & Susanti, Y. V. H. (2022). Using the E-learning gamification tool Kahoot! to learn chemistry principles in the classroom. Procedia Computer Science, 197, 184–191.
[11] Yaron, D. (2003). The ChemCollective – Virtual labs and online activities for chemistry education. Journal of Chemical Education, 80(6), 685.
[12] Savateev, O. (2021). Gamification of an entire introductory organic chemistry course. Journal of Chemical Education, 98(8), 2457–2463.
[13] Cortes Rodríguez, F. J., et al. (2023). MolecularWebXR: Multiuser discussions about chemistry and biology in immersive and inclusive VR. arXiv preprint arXiv:2311.00385.
[14] Gebhardt, P., Yu, X., Köhn, A., &Sedlmair, M. (2022). MolecuSense: Using Force-Feedback Gloves for Creating and Interacting with Molecules in VR. arXiv preprint arXiv:2203.09577.
[15] Mahaffy, P. E., et al. (2018). The Tetrahedral Chemistry Education Approach. Chemistry Education Research and Practice, 19(1), 1–9.
[16] Brinson, J. R. (2015). Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research. Computers & Education, 87, 218–237.