Bio Blocks: Amino Acid 3D Structure Learning Set

Integrating Spatial Computing and Digital Fabrication for Enhanced Molecular Biology Education

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Presenting "Bio Blocks," a project developed independently to revolutionize molecular biology education. This paper delves into the unique combination of an interactive React-based web application and a 3D printed Lego Set designed to facilitate student learning of amino acid structures. In this paper, the project creator outlines the distinctive features of Bio Blocks. The interactive web application enables users to explore and understand 3D amino acid structures, while downloadable STL files allow for the creation of customized Lego-style pieces for hands-on learning. The use of Autodesk Fusion 360 ensures the accuracy and visual representation of the designed structural Lego components. The evaluation methodology encompasses user feedback, engagement metrics, and an assessment of the tool's educational effectiveness. Demonstrative artifacts, including 20 amino acid images, interactive 3D amino acid models, text information about each amino acid, and 3D Lego pieces, illustrate the unique capabilities of Bio Blocks. This project represents a noteworthy advancement in design tools, offering an accessible and engaging means for students to comprehend complex molecular concepts.

CCS CONCEPTS • Spatial Computing • Digital Fabrication • Molecular Biology Education

Additional Keywords and Phrases: 3D Printing, Web application, Human-Computer Interaction

1 INTRODUCTION

Developing cutting-edge teaching resources is more important than ever in the field of molecular biology education. Traditional teaching methods frequently fail to adequately communicate the complex three-dimensional structures of biomolecules, leading students to grapple with abstract ideas. This stark educational challenge has propelled the creation of the "Bio Blocks" project – an initiative developed to bridge the gap between theoretical knowledge and tangible understanding of amino acid structures.

"Bio Blocks" was inspired by the realization that conventional molecular biology teaching approaches frequently fail to provide a thorough understanding of intricate molecular structures, especially those of amino acids. A thorough understanding of the three-dimensional arrangements of amino acids is crucial for students pursuing related subjects and aspiring biologists, as they are vital building blocks in the complex design of proteins. By offering an engaging and practical learning environment that goes beyond the bounds of traditional teaching techniques, our project aims to close this educational gap.

Human-computer interaction (HCI) ideas are included into "Bio Blocks" in order to improve the user experience and make the exploration of amino acid structures more intuitive. The project makes use of a React-based web application to generate an interactive interface that allows users to easily explore, rotate, and navigate the three-dimensional representations of amino acids. The learning experience is made to be not only informative but also interesting and approachable by incorporating HCI principles.

Furthermore, the initiative acknowledges how digital manufacturing and spatial computing may transform molecular biology education. By embracing spatial computing, Bio Blocks endeavors to provide students with a dynamic platform for exploring molecular structures in a spatial context, fostering a deeper and more intuitive understanding. The use of digital fabrication methodologies, specifically via the production of 3D printed Lego-like components, further enhances the tangible and hands-on aspects of the learning experience. With these developments, Bio Blocks hopes to bring in a new phase of molecular biology education, one in which cutting-edge resources work in tandem with conventional teaching strategies to provide students with an immersive and effective educational experience.

2 BACKGROUND AND RELATED WORK

The field of molecular biology education, digital manufacturing tools, and spatial computing presents a wide range of methods designed to improve comprehension and participation. Conventional materials in molecular biology teaching mostly consist of static visual aids and textbooks, providing little opportunities for students to engage with and understand the three-dimensional structures of biomolecules. Although certain tools make use of 3D modeling software, complexity, and technological obstacles frequently make them difficult to use and integrate into educational settings.

2.1 Spatial Computing and Digital Fabrication

There aren't many spatial computing tools that are explicitly designed for amino acid structures; most of them concentrate on general chemical visualization. Although spatial computing technologies such as virtual reality (VR) and augmented reality (AR) have shown promise, hardware limitations prevent widespread application in molecular biology instruction. “In the evaluations, the use of AR applications in the courses are told to have many advantages such as flexibility provided by the system, being safe, intuitive and interactive, enabling students to learn effectively by doing and interacting with the system as they learn complex processes can improve the sense of existence [1].” The cost of VR and AR setups, along with the associated hardware requirements, often poses a barrier for educational institutions and individual users. “For example, quality VR hardware is still somewhat expensive and can be cumbersome to use in a classroom setting [2].”

The ability to create physical representations of molecular structures has progressed significantly thanks to digital manufacturing methods. For instance, the author printed the Lego components required for this project using the Makerspace at the author’s school, albeit it still requires some trial and error to find the most effective way to print the pieces. But in general, the public now has accessible 3D printers thanks to Makerspace. Not to mention that owning a 3D printer at home is getting more and more affordable. However, most of these tools lack the simplicity needed for instructional applications, as they are meant for more experienced users in research contexts and require some familiarity with 3D modeling software. Gaps persist in providing accessible and customizable solutions for students to physically interact with molecular structures.

2.2 Design Solution

“Bio Blocks”, the Amino Acid 3D Structure Learning Set, strategically addresses these gaps. Unlike conventional educational materials, “Bio Blocks” combines spatial computing with an intuitive desktop web application interface, allowing students to explore and manipulate amino acid structures seamlessly. By sidestepping the cost and complexity associated with VR and AR setups, “Bio Blocks” ensures broad accessibility for users across educational levels. Downloading ready-to-print 3D models eliminates the need for prior experience with 3D modeling software like Maya or

Blender. Additionally, the author offers 3D printing instructions utilizing some online content that already exists. For a novice user, this is a one-stop solution.

2.2.1One-Stop Solution.

The user can download the Zip file containing all the Lego pieces needed to create an amino acid by visiting the official website, as shown in Figure 1. A close-up of the files inside the Zip folder can be seen in Figure 2. The 3D printing guidelines are displayed in Figure 3.

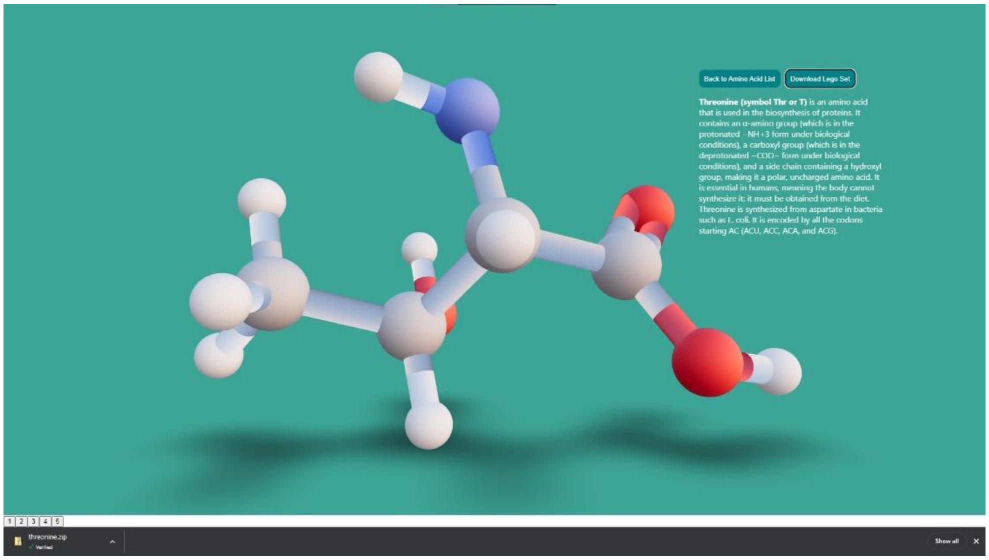
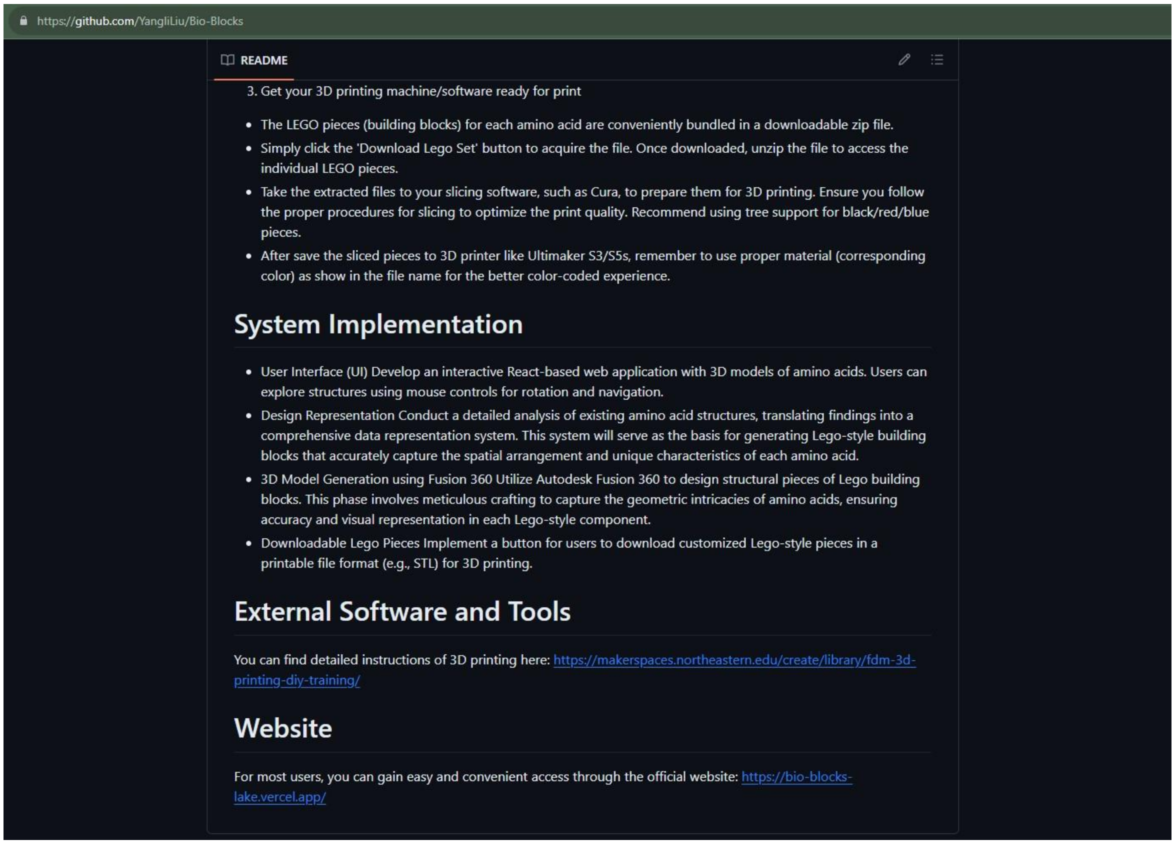


Figure 1: Ready-to-print Zip File. Screenshot by Yangli Liu. (https://bio-blocks-lake.vercel.app/)

Name	Type	Compressed size	Password ...	Size	Ratio
Black2	STL File	89 KB	No	294 KB	70%
Black3	STL File	116 KB	No	297 KB	62%
Black4_1	STL File	94 KB	No	309 KB	70%
Black4_2	STL File	94 KB	No	309 KB	70%
Blue1	STL File	95 KB	No	354 KB	74%
Red1	STL File	133 KB	No	338 KB	61%
Red1 - 1	STL File	133 KB	No	338 KB	61%
Red2	STL File	150 KB	No	422 KB	65%
White_1	STL File	79 KB	No	354 KB	78%
White_2	STL File	79 KB	No	354 KB	78%
White_3	STL File	79 KB	No	354 KB	78%
White_4	STL File	79 KB	No	354 KB	78%
White_5	STL File	79 KB	No	354 KB	78%
White_6	STL File	79 KB	No	354 KB	78%
White_7	STL File	79 KB	No	354 KB	78%
White_8	STL File	79 KB	No	354 KB	78%
White_9	STL File	79 KB	No	354 KB	78%

Figure 2: Close-up of 3D Building Block files. Screenshot by Yangli Liu.



https://github.com/YangliLiu/Bio-Blocks

README

3. Get your 3D printing machine/software ready for print

- The LEGO pieces (building blocks) for each amino acid are conveniently bundled in a downloadable zip file.
- Simply click the 'Download Lego Set' button to acquire the file. Once downloaded, unzip the file to access the individual LEGO pieces.
- Take the extracted files to your slicing software, such as Cura, to prepare them for 3D printing. Ensure you follow the proper procedures for slicing to optimize the print quality. Recommend using tree support for black/red/blue pieces.
- After save the sliced pieces to 3D printer like Ultimaker S3/S5s, remember to use proper material (corresponding color) as show in the file name for the better color-coded experience.

System Implementation

- User Interface (UI) Develop an interactive React-based web application with 3D models of amino acids. Users can explore structures using mouse controls for rotation and navigation.
- Design Representation Conduct a detailed analysis of existing amino acid structures, translating findings into a comprehensive data representation system. This system will serve as the basis for generating Lego-style building blocks that accurately capture the spatial arrangement and unique characteristics of each amino acid.
- 3D Model Generation using Fusion 360 Utilize Autodesk Fusion 360 to design structural pieces of Lego building blocks. This phase involves meticulous crafting to capture the geometric intricacies of amino acids, ensuring accuracy and visual representation in each Lego-style component.
- Downloadable Lego Pieces Implement a button for users to download customized Lego-style pieces in a printable file format (e.g., STL) for 3D printing.

External Software and Tools

You can find detailed instructions of 3D printing here: https://makerspaces.northeastern.edu/create/library/fdm-3d-printing-diy-training/

Website

For most users, you can gain easy and convenient access through the official website: https://bio-blocks-lake.vercel.app/

Figure 3: 3D Printing Guidelines. Screenshot by Yangli Liu. (https://github.com/YangliLiu/Bio-Blocks)

3 RESEARCH GOALS AND OBJECTIVES

The "Bio Blocks" project's research objectives are carefully designed to maximize the potential of digital fabrication and spatial computing to improve molecular biology education. The main goals revolve around offering a novel, user-friendly, and efficient tool that tackles the shortcomings of existing teaching methods.

3.1 Spatial Computing Integration for Accessibility

Integrate spatial computing into molecular biology education through an accessible desktop web application, offering an immersive and user-friendly platform for exploring amino acid structures.

3.2 Digital Fabrication for Tangible Learning

Utilize digital fabrication, specifically 3D printed Lego-style pieces, to provide students with a tangible, hands-on component that enhances the learning process and makes abstract concepts concrete and memorable.

3.3 User-Centric Educational Effectiveness

Examine Bio Blocks's educational efficacy using user feedback, engagement metrics, and evaluations to make sure the program actually helps students understand and remember amino acid structures.

All together, these goals seek to establish a new standard in molecular biology teaching by fusing innovation in technology, accessibility, and efficacy for learners, teachers, and the larger educational community.

4 SYSTEM DESIGN AND IMPLEMENTATION

"Bio Blocks," is a carefully crafted system that combines digital manufacturing components using the Fusion 360 design process with spatial computing features via a React-based web application. An engaging and easily accessible learning experience is guaranteed for consumers with this multimodal approach.

4.1 React-Based Web Application

The development of an interactive web application using React forms the core of the system. Users have an interesting platform to investigate the three-dimensional structures of amino acids thanks to this intuitive interface. By utilizing the concepts of spatial computing, the online application facilitates easy manipulation and navigation of the molecular structures by users. Users are able to examine the details of amino acids in a spatial context by rotating, zooming, and using mouse controls. A smooth learning process is ensured by the React framework, which makes it easier to create an interface that is both visually beautiful and responsive.

4.2 Fusion 360 Design Process

Autodesk Fusion 360 is a 3D design and modeling tool that is used in the system's digital fabrication phase. This stage involves translating the geometrical nuances of amino acids into visually striking and functional Lego-style building blocks. Fusion 360 enables precise structural component creation, guaranteeing that the digital manufacturing procedure complies with the distinct qualities of every amino acid. This stage is essential for the author to build physical components that users can interact with and utilize to reinforce the spatial awareness they have learned from the web application.

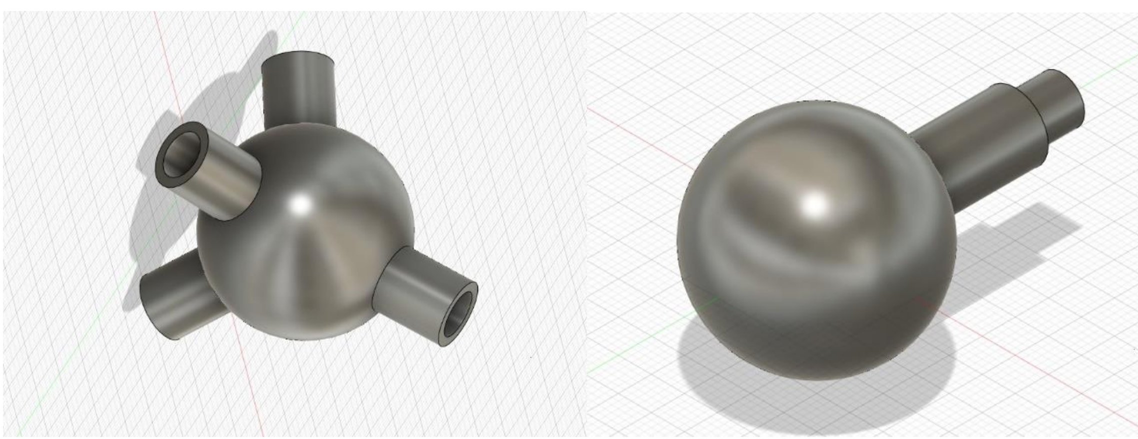


Figure 4: Fusion 360 Design File. Screenshot by Yangli Liu.

4.3 Digital Fabrication Aspects

The finished downloadable STL files, which stand in for the personalized Lego-style pieces, are the result of the Fusion 360 design process. Users can use these files as a blueprint to 3D print their molecular models and participate in digital manufacturing. By adding digital manufacturing, the spatial computing components are enhanced, and users are given a tangible, tactile depiction of the amino acids they have been studying digitally.

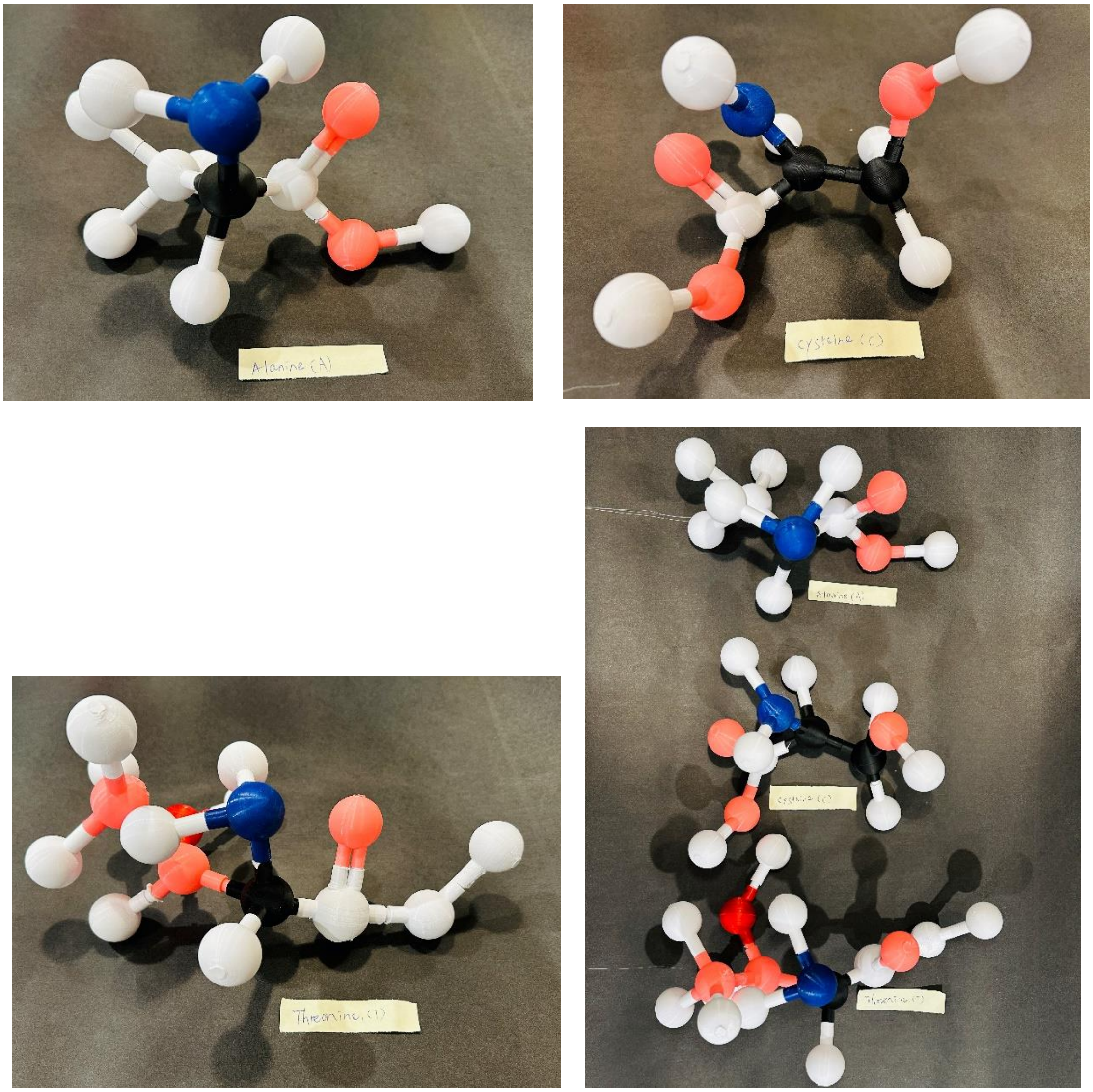


Figure 5: Three Artifacts made with Bio Blocks. Photography by Yangli Liu.

In summary, the Fusion 360 design process and React-based web application enable a seamless integration of digital fabrication elements with spatial computing elements in the design and execution of the Amino Acid 3D Structure Learning

Set. This holistic approach ensures an accessible, engaging, and comprehensive learning experience for students studying amino acid structures.

5 EVALUATION METHODOLOGY

The evaluation methodology for the "Bio Blocks" comprises a series of user tests conducted with two participants. Each user test involves three distinct sessions, carefully designed to assess the effectiveness of the tool in enhancing spatial interaction, ensuring digital fabrication fidelity, and evaluating the overall educational impact. It is tailored to identify and address usability challenges hindering students' comprehension of amino acid 3D structures. Additionally, it seeks to investigate memory-related challenges and enhance retention through tactile learning strategies.

5.1 Traditional Text-Based Learning

Phase 1: Just Reading Theory of Amino Acid Structures

Participants engage in traditional text-based learning to establish a baseline understanding of amino acid structures through theoretical knowledge.

5.2 2D Model Image and 3D Printing Assembly

Phase 1: Watching the 2D Model Image of Amino Acid Structures

Participants transition from text-based learning to a 2D visual representation, enhancing their understanding of amino acid structures.

Phase 2: Timed 3D Printing Assembly

Participants are timed as they assemble 3D printed Lego-style pieces corresponding to the amino acid structures, assessing their ability to translate theoretical knowledge into a tangible, hands-on activity.

Figure 6: 2D Model and 3D Printing Assembly. Photography by Yangli Liu.

5.3 Interactive 3D Model Exploration and Lego Assembly

Phase 1: Interacting with the 3D Model on the Website

Participants explore amino acid structures in a spatial context through an interactive 3D model on the Bio Blocks website, providing an immersive learning experience.

Phase 2: Timed Lego Assembly based on 3D Model Interaction

Participants are timed as they assemble Lego pieces, evaluating the effectiveness of the interactive 3D model in visualizing and recreating molecular structures.

Figure 7: Interactive 3D Model Exploration and Lego Assembly. Photography by Yangli Liu.

This comprehensive methodology combines user feedback, observational studies, and testing sessions to tackle usability issues, while also investigating memory-related obstacles and putting methods in place to improve retention using tactile learning methodologies. Through the use of this structured evaluation methodology, Bio Blocks aims to obtain a comprehensive understanding of its impact on spatial interaction, digital fabrication, and educational outcomes by combining quantitative and qualitative data.

6 RESULTS AND FINDINGS

6.1 Participant 1

6.1.1Feedback

Just Reading Theory: The participant expressed dissatisfaction with the traditional text-based learning approach, highlighting its inefficacy in aiding the reconstruction of the molecular models. The rating was notably low at 1/10.

Watching the 2D Model Image: The introduction of a 2D visual model improved the participant's understanding, yet difficulties in grasping bond structures were noted. The rating for this phase was moderate at 6/10.

Interacting with the 3D Model: The interactive 3D model proved to be the most effective for the participant. The dynamic exploration, coupled with the ability to zoom in on structures, contributed to a better understanding. The participant found the process enjoyable, resulting in a higher rating of 9/10.

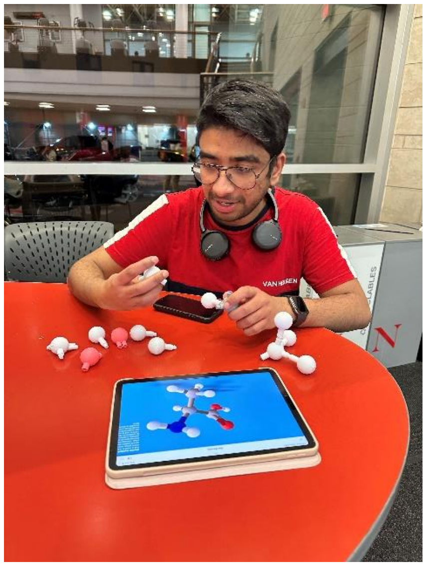


Figure 8: Performance in Lego Assembly Tests. Photography by Yangli Liu.

6.1.2 Performance in Tests

This participant did two sets of tests.

Alanine: The participant struggled with the 2D Model, eventually giving up. However, when interacting with the 3D model, the participant succeeded in reconstructing Alanine within 3 minutes and 56 seconds. A significant improvement was observed, indicating the effectiveness of the interactive 3D model.

Glycine: The participant succeeded in the 2D Model assembly, completing it in 3 minutes and 9 seconds. The Interactive 3D Model Exploration and Lego Assembly for Glycine were accomplished in a swift 1 minute and 23 seconds, showcasing increased efficiency and understanding of the overall system.

6.2 Participant 2

6.2.1Feedback

Just Reading Theory: The participant rated traditional text-based learning as ineffective, providing a low rating of 3/10.

Watching the 2D Model Image: The introduction of the 2D model improved the participant's understanding, receiving a moderate rating of 6/10.

Interacting with the 3D Model: The interactive 3D model proved highly effective for the participant, earning a high rating of 9/10. However, the participant expressed a desire for a dedicated step-by-step guide for construction along with component requirements.

6.2.2 Performance in Tests

Asparagine: The participant succeeded in both the 2D Model Image and 3D Model Assembly. Completing 2D Model and 3D Printing Assembly in 9 minutes and 46 seconds. The Interactive 3D Model Exploration and Lego Assembly for Asparagine were accomplished in a more efficient 4 minutes and 23 seconds.

6.3 Overall Observations

Effectiveness of Interactive 3D Model: Both participants demonstrated improved understanding and efficiency during the Interactive 3D Model Exploration and Lego Assembly phase, indicating the effectiveness of the interactive 3D model in facilitating comprehension and reconstruction. Participant 2's feedback highlighted a desire for a dedicated step-by-step guide, suggesting an opportunity to enhance the tool with additional instructional resources.

Ultimately, the data and conclusions point to a major improvement in the understanding and reconstruction of amino acid structures provided by Bio Blocks, especially when it comes to the interactive 3D model. The tool has the potential to have a positive educational impact, as seen by the observed improvements in users' performance, and user feedback offers insightful information.

7 CONCLUSION AND FUTURE WORK

The evaluation of the Amino Acid 3D Structure Learning Set, “Bio Blocks,” has provided important information about improving memory and usability in molecular biology education. An essential component that greatly enhanced learning efficiency and comprehension was the interactive 3D model.

In future iterations, the focus will be on refining the design of Lego pieces within Bio Blocks to ensure optimal assembly accuracy, addressing the author’s feedback about potential challenges in the final amino acid reconstruction of a few specific amino acids. Additionally, the author plans to incorporate a dedicated step-by-step guide and component requirements to provide users with enhanced instructional resources, catering to varied learning preferences. Continuous user testing and feedback will drive iterative design improvements, ensuring Bio Blocks evolves as a user-centered educational tool, contributing to an effective and engaging platform for learning amino acid 3D structures.

In conclusion, Bio Blocks aims to be an approachable, entertaining, and all-inclusive resource that meets a range of different needs through interactive exploration and real, 3D-printed models. From students in K-12 and higher education studying biology to educators seeking innovative teaching aids, and even parents facilitating at-home learning experiences for their science-minded children, Bio Blocks offers a versatile and engaging platform. It emerges as a promising educational tool for molecular biology, harnessing the power of interactive 3D models to deliver a dynamic and captivating learning experience.

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A APPENDICES

Official Website of “Bio Blocks”: https://bio-blocks-lake.vercel.app/