Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
ASEE
Paper ID #46975

Colorful Connections: Building Linked Lists with Playdough

Dr. Farha Jahan, Ohio Northern University
Dr. Heath Joseph LeBlanc, Ohio Northern University

Heath J. LeBlanc is a Professor and Chair of the Electrical and Computer Engineering and Computer Science (ECCS) Department at Ohio Northern University. He received his MS and PhD degrees in Electrical Engineering from Vanderbilt University in 2010 and 2012, respectively.

Colorful Connections: Building Linked Lists with Play-Doh

Farha Jahan	Heath LeBlanc
f-jahan@onu.edu	h-leblanc@onu.edu
ECCS Department	ECCS Department
Ohio Northern University	Ohio Northern University

Abstract

Linked lists are fundamental data structures in computer science, but their abstract nature can pose challenges for students, particularly those with diverse backgrounds and limited mathematical preparation. This paper presents a novel approach to teaching linked lists using Play-Doh as a hands-on, interactive manipulative combined with an analogy. The activity involves students creating and manipulating Play-Doh ”trains” to represent linked lists, performing operations such as insertion, deletion, and traversal. A post-activity survey of students in an introductory data structures and algorithms course reveals a significant improvement in their understanding of linked lists, high levels of engagement, and a preference for the Play-Doh activity over traditional teaching methods. These findings suggest that the Play-Doh activity and analogy can effectively bridge the gap between abstract concepts and real-world applications, making linked lists more accessible and comprehensible to all students. This paper contributes to the growing body of research on active learning and the use of manipulatives in computer science education, offering a practical and engaging approach to teaching linked lists.

1 Introduction

Miss Lily, a kindergarten teacher, wants to create a colorful Play-Doh train where each car can be easily added or removed without disrupting the others. This playful scenario mirrors a fundamental concept in computer science: linked lists. Linked lists are dynamic data structures that store data in interconnected nodes. They play a crucial role in various computer science applications, from managing memory allocation to implementing complex algorithms. However, students often struggle with understanding linked lists due to their abstract nature and the challenge of visualizing their structure and manipulation.

This challenge is particularly pronounced in introductory computer science courses with diverse student populations, such as those with students pursuing a computer science minor. These students often have limited mathematical backgrounds, and the course may include majors from across the university, with no discrete mathematics or calculus courses required as prerequisites. This variation in the mathematical background creates a gap in the student’s readiness to grasp abstract data structures like linked lists.

This paper presents a novel approach to teaching linked lists using Play-Doh as a hands-on, interactive tool coupled with an analogy. By creating and manipulating Play-Doh trains, students can gain a tangible understanding of how linked lists work and how individual nodes can be added, removed, or rearranged. The main objectives of this paper are to: (1) describe the design and implementation of the Play-Doh activity, (2) demonstrate its effectiveness in improving student comprehension of linked lists, and (3) advocate for the integration of active learning strategies in computer science education. This work contributes to the growing body of research on the use of manipulatives and real-world analogies in teaching abstract computer science concepts, offering a practical and engaging way to enhance student learning and motivation, especially for students with diverse academic backgrounds.

2 Literature Review

Active learning has become increasingly recognized as a crucial pedagogical approach in computer science education [1]. Unlike traditional passive learning methods, active learning engages students in the learning process through activities, discussions, and problem-solving, fostering deeper understanding and retention of concepts [2]. This is particularly important in computer science, where abstract concepts can be challenging for students to grasp.

Hands-on activities and manipulatives play a significant role in making these abstract concepts more concrete and accessible [3]. By providing tangible representations of data structures and algorithms, manipulatives cater to diverse learning styles and allow students to physically interact with the concepts they are learning [4]. For example, Ramabu et al. (2016) [3] found that using physical blocks to represent data structures significantly improved the understanding of algorithms by students.

Analogies and metaphors further enhance the learning process by bridging the gap between students' existing knowledge and new computer science concepts [5]. A well-chosen analogy can provide a familiar framework for understanding complex ideas, making them more relatable and easier to remember [6]. In this paper, the analogy of a train, with its interconnected cars representing nodes in a linked list, serves as an intuitive and engaging analogy for students to grasp the fundamental structure and operations of linked lists.

While various approaches exist for teaching linked lists, including traditional lectures, visualizations, and interactive simulations, [7] challenges remain in ensuring that students truly understand the dynamic nature and practical applications of this data structure [8]. Zhang (2015) emphasizes the importance of teaching linked lists in the context of problem-solving, connecting them to real-world scenarios to enhance student motivation and understanding through games. [9]

This paper addresses these challenges by introducing a novel approach to teaching linked lists using Play-Doh as a hands-on, interactive manipulative. This approach aligns with the principles of active learning, leveraging both hands-on activities and the power of analogy to enhance student comprehension. By providing a tangible and relatable representation of linked lists, the Play-Doh activity aims to bridge the gap between abstract concepts and real-world applications, making the learning process more engaging and effective for students with diverse academic backgrounds.

3 Problem Statement

Despite their importance, linked lists present a significant pedagogical challenge. Their abstract nature, involving interconnected nodes and dynamic memory management, often leads to confusion and frustration among students. Traditional teaching methods, such as lectures and textbook explanations, may fall short of providing an engaging understanding of how linked lists work and how they are used in real-world applications.

This difficulty is further compounded when teaching students with diverse backgrounds and varying levels of mathematical preparation, such as those found in introductory computer science courses that include students pursuing a minor in the field. These students may lack formal training in discrete mathematics or data structures that would facilitate a deeper understanding of linked lists.

Therefore, there is a need for more engaging and accessible pedagogical approaches that can bridge this gap and make linked lists more comprehensible to all students. This problem calls for innovative teaching methods that can provide memorable experiences, facilitate visualization, and connect the abstract concepts of linked lists to real-world applications.

4 Proposed Solution

To address the challenges of teaching linked lists to students with diverse backgrounds, this paper proposes a novel approach that utilizes Play-Doh as a hands-on, interactive manipulative. This approach is grounded in the principles of active learning and aims to:

Provide a Concrete Representation: By allowing students to physically create and manipulate Play-Doh ”trains” with individual ”cars” representing nodes, the abstract concept of a linked list is transformed into a tangible and relatable experience.

Facilitate Visualization: The act of connecting and disconnecting Play-Doh cars with ”links” (e.g., toothpicks) helps students visualize the interconnected nature of nodes in a linked list and the dynamic relationships between them.

Enhance Engagement: The playful and creative nature of Play-Doh encourages active participation and fosters a more enjoyable learning environment, potentially increasing student motivation and interest in the topic.

Connect to Real-World Applications: By framing the activity within the context of a real-world scenario (Miss Lily’s train as an educational experience for her kindergarten class), students can better understand how relatable linked lists can be.

This Play-Doh activity offers a unique and engaging way to introduce linked lists, catering to diverse learning styles and promoting a deeper understanding of this fundamental data structure. The hands-on experience, combined with the relatable analogy of a train, aims to bridge the gap between abstract concepts and real-world applications, making linked lists more accessible and comprehensible to all students.

5 Methodology

This study employs an active learning approach to teach linked lists using a hands-on Play-Doh activity. The activity has been designed to provide a concrete and engaging experience for students with diverse backgrounds in an introductory computer science course at Ohio Northern University. The participants included 13 students enrolled in Data Structure and Algorithm 1 during the Fall 2024 semester. This course typically includes students pursuing a computer science minor for an undergraduate degree with varying levels of mathematical preparation.

5.1 Play-Doh Activity

The Play-Doh activity is conducted in a 50-minute classroom setting, with students divided into groups of two. One student in each group builds the train, while the other student jots down the steps required for each operation. Each group receives four containers of Play-Doh of different colors to make the cars. The color of the car indicates what its load is. The cars of the train are linked together using toothpicks, like chain links between the cars as a singly linked list. The students got creative in their representations of the cars and train, as shown in Figure 1.

Figure 1: Examples of Play-Doh Train Models created by students.

Materials:

- Play-Doh of various colors
- Toothpicks

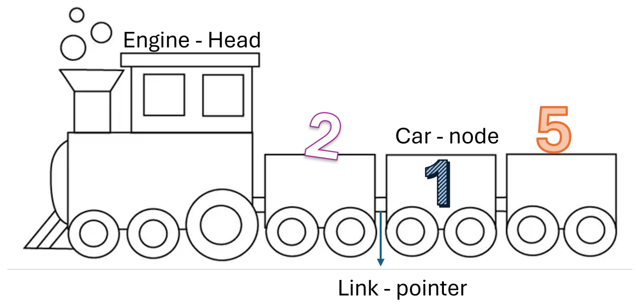

Figure 2: The Train Analogy

- Optional: Markers and small labels

In the analogy, the train cars are the nodes and the toothpicks are the linking members (e.g., pointers), as shown in Figure 2. Since the head node of a linked list has a head pointer, a toothpick is added to the lead car, called the engine of the train, which signifies that it is the engine (and can, for example, represent the smoke stack, or chimney, on the engine). However, in the real world, the engine car does not carry a load. To make this analogy work, we make special rules as stated below:

- First car becomes the engine
- Engine also carries a load
- A car can be inserted in front of the engine. Now, that car becomes the engine.
- Keep track of the engine.
- The Last car in the train, the caboose, has a place for the link but is not connected.

Although the analogy has clear limitations, it helps to make keeping track of the head node pointer more memorable since any new head node needs to be converted to an engine car, or any old engine car has its chimney removed and passed to the next car.

The activity is structured as follows:

1. **Introduction and Motivation (10 minutes):** The instructor introduces the concept of linked lists and presents the scenario of ”Miss Lily’s train” (an excerpt of which is described in the Introduction) to establish a relatable context for understanding linked lists.
2. **Construction (10 minutes):** Students are instructed to construct their Play-Doh trains, with each ”car” representing a node in a linked list. Toothpicks were used as the ”links” connecting the cars, representing pointers. Each car is also assigned a ”data” value, represented by its color or by using markers/labels to write values on the cars. Several examples of Play-Doh trains constructed by students are shown in Figure 1.
3. **Manipulation (20 minutes):** Students are guided through a series of operations on their trains, simulating common linked list operations:
   - **Insertion:** Adding a new car to the beginning, middle, or end of the train.

- **Deletion:** Removing a car from the beginning, middle, or end of the train.
- **Traversal:** Following the links (toothpicks) from the head of the train to the end, simulating the traversal of the linked list.

4. **Discussion and Reflection (10 minutes):** Students engage in a guided discussion, reflecting on their observations and drawing connections between the Play-Doh model and the abstract concepts of linked lists. They are encouraged to articulate the relationship between the physical actions performed on the Play-Doh train and the corresponding operations in a linked list data structure.

5.2 Post-Activity Survey

Several weeks following the activity, students individually completed a post-activity survey. This was a reflection on the activity after they had completed programming assignments and an exam on the topic. The survey consisted of 11 questions, including a mix of Likert scale items, multiple-choice questions, and open-ended questions. The survey aimed to gather feedback on the following aspects:

- **Understanding:** Students' self-assessed understanding of linked lists before and after the activity (Likert scale).
- **Engagement:** Students' level of engagement with the activity (Likert scale).
- **Effectiveness:** Students' perception of the activity's effectiveness in comparison to traditional methods (Likert scale).
- **Specific Learning Components:** Which parts of the activity were most helpful in understanding linked lists (multiple choice with the option to select all that apply)?
- **Challenges:** Which aspects of linked lists do students still find challenging after the activity (multiple choice with the option to select all that apply)?
- **Open-ended feedback:** Students were given opportunities to provide detailed feedback on their experience, including:
  - What they liked most about the activity.
  - Any difficulties encountered and how they overcame them.
  - Explanation of the analogy between the train and the linked list.
  - How collaboration contributed to their learning.
  - Suggestions for improving the activity in future classes.

The survey data was analyzed to identify key trends and insights related to the effectiveness of the Play-Doh activity in enhancing student understanding and engagement with linked lists. Ethical considerations, such as informed consent and anonymity, were ensured by applying for approval through the Institutional Review Board (IRB) of Ohio Northern University, approved under protocol FJ-EN-103024-1.

6 Results

This section presents the key findings from the post-activity survey, highlighting the impact of the Play-Doh activity on student understanding of linked lists and their engagement with the learning process. The assessment results are based on a class of 13 students out of which 11 took the survey.

6.1 Understanding of Linked Lists

The survey data revealed a significant improvement in students' self-assessed understanding of linked lists after the Play-Doh activity.

Table 1: Students' self-assessed understanding of linked lists before and after the Play-Doh activity.

Understanding Level	Before Activity	After Activity
Very Well	1 (9%)	5 (45%)
Somewhat well	1 (9%)	6 (54.5%)
Not at all	9 (81.8%)	0 (0%)

As shown in Table 1, the number of students who reported understanding linked lists "Very Well" increased from 1 (9%) before the activity to 5 (45%) after the activity. Notably, none of the students reported "Not at all" understanding linked lists after the activity, compared to 9 (81.8%) before. This improvement is reflected in student feedback, such as one student who stated, "I liked that I was able to better visualize what was actually happening when we use linked lists. It is very helpful to be able to see what is going on compared to [just having] some abstract concept we need to visualize in our heads."

6.2 Engagement with the Activity

The majority of students found the Play-Doh activity to be engaging.

Figure 3 illustrates that 8 (72.7%) students found the activity "Very engaging" and 3 (27%) found it "Moderately engaging." Zero students reported the activity as "Not engaging at all." This positive response to the activity is evident in comments like, "It was a fun representation of linked lists and how to visualize them."

6.3 Effectiveness of the Physical Model

Most students agreed that the physical model (Play-Doh train) helped them understand linked lists better than traditional methods.

As depicted in Figure 4, 8 (72.7%) students either "Strongly agreed" or "Agreed" that the Play-Doh activity was more effective than traditional methods like lectures or textbooks. One student commented, "It helped me visualize how linked lists work with the pointer connections, and allowed me to be able to apply the concepts that I learned throughout the activity in my code later on."

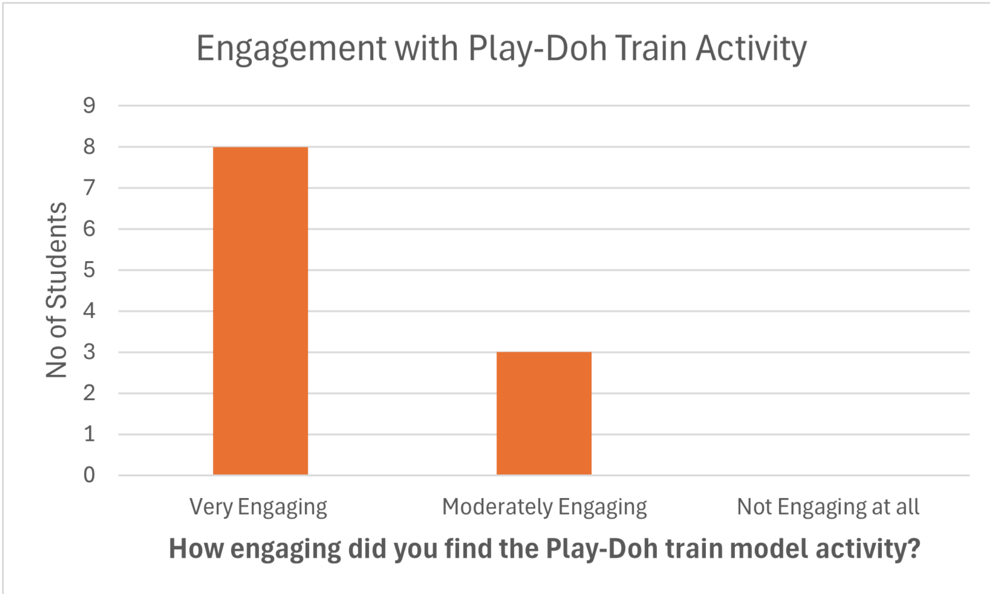

Figure 3: Students' level of engagement with the Play-Doh activity.

6.4 Specific Learning Components

The survey also explored which specific aspects of the activity were most helpful in understanding linked lists. The most frequently cited components were:

- Visualization of node connections (7 students)
- Adding/removing train cars (insertion/deletion) (6 students)
- Discussing the activity with peers (5 students)
- Seeing how data and pointers interact (5 students)

6.5 Challenges and Suggestions

While the activity was generally well-received, some students still found certain aspects of linked lists challenging, such as memory and pointers (4 students) and traversal (2 students). These topics are not as well supported by the train activity. Students also provided valuable suggestions for improvement, such as providing clearer instructions ("Improve some of the descriptions of what the activity is. There were times when I was not 100% sure what we were supposed to do.") and explaining the addition of train cars in the middle in more depth.

7 Discussion

The results of this study demonstrate the potential of using Play-Doh as a hands-on, interactive tool for teaching linked lists to students with diverse backgrounds. The significant improvement in students' self-assessed understanding, coupled with the high levels of engagement and positive

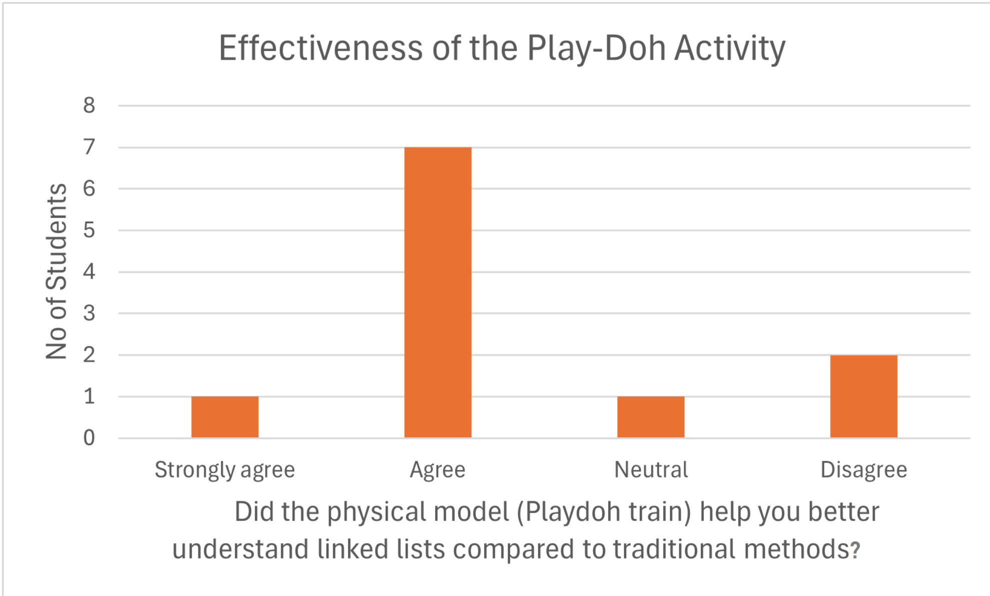

Figure 4: Students' perception of the effectiveness of the Play-Doh activity compared to traditional methods.

feedback, suggests that the Play-Doh activity was effective in making this abstract data structure more concrete and accessible.

7.1 Connecting Results to the Literature

These findings align with existing research on active learning and the use of manipulatives in computer science education. Freeman et al. (2014) [1] highlight the efficacy of active learning techniques in improving student learning outcomes, and Bonwell & Eison (1991) [2] emphasize the importance of creating an engaging learning environment. The Play-Doh activity embodies these principles by actively involving students in the learning process and providing a stimulating and enjoyable experience.

Furthermore, the use of Play-Doh as a manipulative is supported by research on the benefits of tangible technologies in education. Price et al. (2013) discuss the potential of tangible objects to enhance learning through hands-on experiences, and Ramabu et al. (2021) [3] specifically demonstrate the effectiveness of manipulatives in teaching computer science concepts. The Play-Doh activity leverages the tactile and visual nature of the manipulative to provide a concrete representation of the abstract linked list structure.

The train analogy employed in the activity also resonates with research on the use of analogies and metaphors in teaching computer science. Saxena et al. (2023) and Sanford et al. (2014) discuss the power of analogies to bridge the gap between students' existing knowledge and new concepts. The train metaphor provides a familiar and relatable context for understanding the interconnected nature of nodes in a linked list.

7.2 Addressing Challenges and Limitations

While the Play-Doh activity showed promising results, it is important to acknowledge its limitations. Some students still found certain aspects of linked lists challenging, such as memory management and pointers. This suggests that the activity may need to be supplemented with additional instructional strategies to address these more complex concepts.

Furthermore, the small sample size of this study limits the generalizability of the findings. Future research with larger and more diverse student populations is needed to further validate the effectiveness of this approach.

It is worth mentioning that the activity was followed by lecturing and coding practice in C++ representing the train model as a singly linked-list. The train was represented as the 'Class' while the car nodes were represented as a 'struct' data structure. This activity provides an opportunity for the majority students who are not as well served by lecture alone to have alternative teaching methods to learn the material.

7.3 Implications for Practice and Future Research

This study has implications for computer science educators seeking to enhance their teaching of linked lists. The Play-Doh activity offers a practical and engaging way to introduce this data structure, particularly for students with diverse backgrounds and limited mathematical preparation. By providing a concrete, visual, and interactive experience, the activity can help students develop a deeper understanding of linked lists.

Future research could explore the following:

- Investigating the long-term impact of the Play-Doh activity on student learning and retention.
- Comparing the effectiveness of the Play-Doh activity to other instructional methods, such as simulations.
- Adapting the activity for other data structures and algorithms.
- Exploring the use of Play-Doh in online or blended learning environments.

By continuing to investigate and refine innovative approaches like the Play-Doh activity, we can enhance the learning experience for all students and promote a deeper understanding of computer science concepts.

8 Conclusion

This paper presents a novel approach to teaching linked lists using Play-Doh as a hands-on, interactive manipulative. The study investigates the effectiveness of this approach in an introductory data structures and algorithms course with students from diverse backgrounds, including those pursuing a computer science minor with limited mathematical preparation.

The results demonstrate that the Play-Doh activity significantly improved students' self-assessed understanding of linked lists, fostered high levels of engagement, and was perceived as more effective than traditional teaching methods. Students particularly valued the visualization of node connections, the hands-on manipulation of the Play-Doh train, and the opportunity to discuss the activity with their peers.

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