Knowledge Net: Fostering Children's Understanding of Knowledge Representations Through Creative Making and Embodied Interaction in a Museum Exhibit

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ABSTRACT

As young people increasingly use AI in their daily lives, it is imperative to foster these learners' AI literacy. We present *Knowledge Net*, a collaborative tangible tabletop museum exhibit aimed at teaching users about knowledge representations, which are central to understanding AI and understudied in AI education research. In this exhibit, we center creative making and embodied interaction by allowing learners to craft the appearance, behaviors, and traits of characters in a virtual world by manipulating semantic networks. Our poster features the exhibit design and corresponding rationale, and this paper contributes an exploration of how creative making and embodied interaction can be utilized to teach young learners about knowledge representations–and AI more broadly–in informal learning environments.

CCS CONCEPTS

• **Human-centered computing** → **User interface design**; **Interactive systems and tools**; • **Social and professional topics** → **Informal education**.

KEYWORDS

informal learning, museum exhibit, AI literacy, prototyping, design research, tangible user interfaces, AI education, knowledge representation

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1 INTRODUCTION

Public access to artificial intelligence (AI) is expanding and AI technology is increasingly integrated into middle school learners' (ages 10-14) everyday experiences such as browsing social media, completing schoolwork, and using in-home voice assistants such as Amazon Alexa. Middle school students are at a critical age in which they are forming their personal identities and career choices alongside rapidly advancing and publicly-accessible AI technologies. As a result, it is necessary to foster *AI literacy*, a set of competencies that ensure individuals without technical backgrounds can critically and competently evaluate and use AI [16]. Much recent work has focused on introducing AI education into formal K-12 classroom environments [32]. However, less work has explored the introduction of AI education into informal learning environments, which serve a critical role in public science and technology literacy [8]. Thus, there is a need for further research how to introduce AI education in informal learning environments, such as museums. Two design features that have been shown to be particularly well-suited for both fostering interest in and understanding of computing as well as engaging groups in museums are *creativity* [5, 8, 14] and *embodiment* [11–13, 28].

In this paper, we present *Knowledge Net*, an interactive, collaborative museum exhibit focused on teaching about knowledge representations, the structures that model information within a computer system [22]. Knowledge representations are a central AI concept and are one of the five "big ideas" of AI defined by the AI4K12 working group (a team of AI experts and K-12 educators working to develop standards for K-12 AI education) [32]. Our central research question is: *How can we design interactive museum exhibits to encourage interest development in and learning about knowledge representations among learners without a computer science background by using embodiment and creative making?*

This paper will present the design of the *Knowledge Net* exhibit and the theory on which we have based this design. As we continue iterating on the exhibit interface, we plan to conduct user studies in collaboration with the Museum of Science and Industry, Chicago in order to evaluate how the exhibit facilitates learning in a museum context.

2 RELATED WORK

2.1 AI Education for Middle School Students

In recent years, much research has explored AI education in formal K-12 education. The AI4K12 initiative is developing guidelines for AI education at different levels within K-12 curricula [32]. Moreover, many researchers in education and HCI have developed their own curricula for education in formal settings [2, 7, 30, 33, 34].

While AI is being introduced in formal K-12 education, less work has investigated how to teach about AI in informal learning environments. Furthermore, few museum exhibits have focused specifically on teaching AI concepts to middle school age learners. Existing exhibits have a more holistic approach to teaching about AI, such as the Relayer Group's *Artificial Intelligence: Your Mind and the Machine* exhibit. This exhibit teaches about the history of AI and features activities in which users can interact with AI technologies to learn about deep learning, neural networks, computer vision, and other concepts.

2.2 Knowledge Representations

In multiple frameworks dedicated to fostering AI literacy for young learners, knowledge representations have been established as a central concept. In the AI4K12 initiative, one of the five "big ideas" of AI is that "Agents maintain models/representations of the world and use them for reasoning" [32]. This idea emphasizes representation as a key aspect of intelligence.

Furthermore, in recent work *AI literacy* has been defined as "a set of competencies that enables individuals to critically evaluate AI technologies; communicate and collaborate effectively with AI; and use AI as a tool online, at home, and in the workplace" [16]. One such competency advises that learners should be able to "understand what a knowledge representation is and describe some examples of knowledge representations" in order to achieve broader AI literacy [16].

Several learning experiences have been developed to teach middle school students about knowledge representations. In one experience, students learn about knowledge-based systems through an activity in which they teach a robot how to play rock, paper, scissors [2]. In another experience, learners play "mini chess" against each other while acting as a computer that must follow predetermined rules in order to understand rule-based systems [15]. However, these activities lack a creative element for users that has been shown to foster personal connection to the learning experience [6, 9, 21].

This exhibit focuses on the *semantic network*, a type of knowledge representation in which nodes represent objects and labeled edges represent associations between objects [23]. Semantic networks useful for many AI technologies that are relevant in middle schoolers' daily lives; for example, search engines utilize semantic networks to identify topics that are relevant to the search query in order to provide accurate results.

2.3 Previous Iterations

Our team has previously designed *Knowledge Net* activity boxes (Figure 1, left), in which users can use physical tiles and arrows to construct a *semantic network*. These boxes were designed for use by parents and children in at-home learning environments.

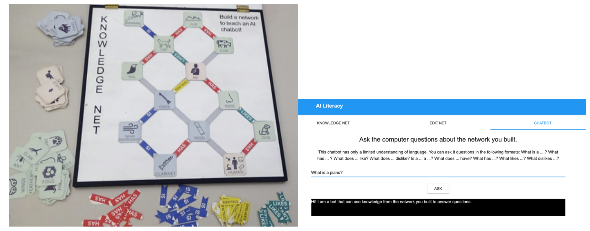

Figure 1: Left: *Knowledge Net* activity box. Right: activity box chatbot

In a previous iteration, users interacted with a chatbot (Figure 1, right) that answered questions based on their constructed networks (e.g., "What does a cat have?" "A cat has paws"); in a later iteration, our system used a data-to-text transformer to generate a story using the constructed network [18, 19]. We conducted user tests with the chatbot version of the activity and found that while network construction was engaging for families and spurred discussion, many families failed to make the connection between the network they built and the chatbot interaction [20]. In the iteration we present in this paper, we aim to improve upon the activity design and also update the activity for a museum setting. In the following sections, we describe how we updated the design of the activity to support multi-user interaction, incorporate creativity in order to foster user interest in AI, and provide immediate visual feedback to aid in user understanding of the AI system and allow for iteration [20, 35].

3 DESIGN THEORY

3.1 Learning Outcomes

The design of *Knowledge Net* is based on four learning outcomes we want users to take away from the exhibit. These learning outcomes are supported as valuable objectives by both the AI4K12 framework [32] and the AI literacy competency framework [16].

Our first objective is for users to understand that *AI uses organized formats ("knowledge representations") to store information about the world.* This learning outcome corresponds to one of the "key insights" for the Representation & Reasoning "big idea" of AI4K12–that representations are data structures [32]. It also corresponds to the AI literacy competency in which users can identify and explain representations [16].

Our second learning outcome is that *all ways of storing information have limits on what they can show about the world.* This outcome maps to the AI literacy competency in which learners can identify the strengths and weaknesses of AI [16]. Additionally, foundational literature on knowledge representations identifies the limitations of such representations as a key idea [22].

Our third learning outcome is that *AI needs to be programmed by people in order to have knowledge.* This outcome is supported by the AI literacy competency focused on understanding the role humans play in programming/training AI [16].

Our final learning outcome is that *networks are one way AI understands ideas and how they connect.* This objective maps to the more specific concept of symbolic representations described in the AI4K12 guidelines [1]. The guidelines suggest that learners between grades 6 and 8 should understand how semantic networks function and what they represent.

While we utilize the specific data structure of a semantic network, our primary goal is for users to understand what a knowledge representation is through this exhibit. These four learning outcomes summarize the most important aspects of this term, while bearing in mind the brief nature of users' interactions with museum exhibits [3].

3.2 Embodied Interaction and Creative Making

We utilize *embodied interaction* and *creative making* as key features in our design, as we hypothesize that they will foster visitor interest, engagement, and learning.

We define *embodied interaction* as encompassing both using the body to control the exhibit and engaging in bodily sensemaking to understand the exhibit content. Prior work on tangible user interfaces has shown that they can be effective at rapidly engaging visitor groups in museums [17] and leading to deeper interactions [10]. In addition, previous research has shown that knowledge of one's own body can facilitate understanding of abstract concepts, and this "body knowledge" can be extended to other virtual or physical objects–e.g.,a digital "turtle" that is programmed to draw lines as it moves in a two-dimensional space [25]. Thus, we hypothesize that using both a tangible, multi-touch user interface and leveraging learners' "body knowledge" in a simulated environment can allow learners to better understand the mappings between their inputs and AI output in our exhibit and allow them to predict the AI output.

Creative making refers to the production of personally relevant artifacts, especially those that persist beyond the exhibit interaction. By designing an experience in which learners use knowledge representations to produce creative, personally relevant artifacts, we hypothesize that learners will perceive AI more generally as relevant [8, 14]. Prior work has shown that creative making activities foster interest in computing, particularly amongst underrepresented groups [6, 21, 24]. Creative, open-ended exploration is also critical to fostering engagement in free-choice learning environments such as museums [14].

4 KNOWLEDGE NET EXHIBIT DESIGN

4.1 Overview

Knowledge Net features a terrarium-themed world in which each user can design and control one of our four characters (Figure 2) by building a semantic network representing that character on a collaborative tangible touch table. We have selected a terrarium theme due to its gender-neutral aesthetic and its role as a miniature "world" featuring a variety of characters. Users can control features of their character such as their hobbies, relationships to other characters, and physical attributes such as body color, shoes, and accessories. For example, the learner can create a network conveying that "Filbert is blue" and "Filbert has a palette" (Figure 3, left), and Filbert's body would correspondingly appear blue and be holding a color palette (Figure 3, right).

Figure 2: *Knowledge Net* characters (Left to right: Bliff, Pajama, Snedgar, Filbert)

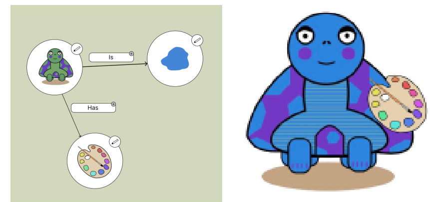

Figure 3: Example network and corresponding output

Users can select character features from a drop-down list. Here, we utilize creative making by allowing users to design their own characters through manipulation of a knowledge representation. Additionally, the character creation element allows users to physically manipulate the exhibit and receive immediate visual feedback on their inputs; learners can also use their own "body knowledge" to predict how their character will look and act based on their inputs.

The exhibit has four stations at which four different users can each control a unique character (Figure 4). The four characters "live" in the center of the table, where they interact based on the characteristics defined by the users. We decided to include multiple stations (rather than one single workspace) in order to allow for multiple users to collaborate, while reducing issues related to user territoriality [14, 29]. Based on our exhibit setup, we determined the design could accommodate a maximum of four users, as well as the center "world".

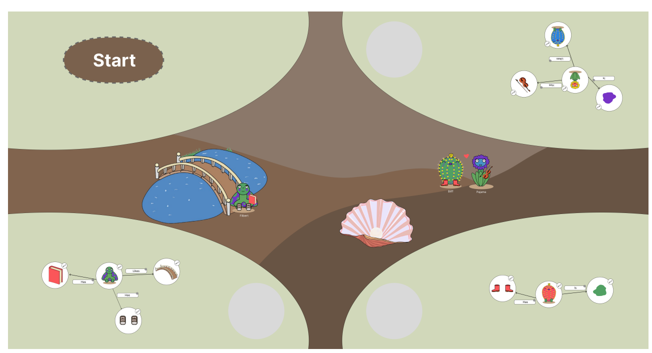

Figure 4: *Knowledge Net* four-station design

Characters behave according to their graph by displaying a heart when they're near characters or qualities they like, and displaying a broken heart when near characters or qualities they dislike. For example, if a character likes another character, they would display a heart when near that character in the center "world". Moreover, if a character likes a certain color, they would display a heart when

Table 1: Mapping of Learning Outcomes to Design Choices

Learning Outcome	Design Aspect
AI uses organized formats ("*knowledge representations*") to store information about the world.	Users control the characteristics of characters by creating and modifying a semantic network, a type of knowledge representation.
All ways of storing information have limits on what they can show about the world.	Users can only control their designated character through their semantic network. They can also only control certain aspects of the character through their semantic network.
AI needs to be programmed by people in order to have knowledge.	The characters only look and act based on the graph that the users create. If the user inputs conflicting information, the computer may produce unexpected output such as odd character appearance or behavior.
Networks are one way AI understands ideas and how they connect.	Characters and their qualities are represented by nodes and relate to each other through labeled arrows.

near that color. For example, if a character likes the color blue, they would display a heart when near a blue character. Based on previous research on designing intuitive interactions [4], these clear and intuitive input-output mappings will facilitate understanding of the relationship between the knowledge representation and character design and behavior. We predict based on prior work that it will also aid learners in iterating on their networks to achieve desired outcomes [20].

Users can also input conflicting facts, such as that Filbert likes Bliff and Filbert dislikes Bliff. In this case, Filbert would display both a heart and a broken heart when near Bliff in order to demonstrate the conflicting inputs. We allow for conflicting inputs in order to create a low barrier of entry to the activity for users. Rather than outputting an error message, which may discourage users, we aim to allow users to observe this unexpected behavior and identify what aspects of their input caused it, as seen in other simulated embodied learning environments [26]. This can also lead to interesting and fun emergent behavior of the characters, facilitating playful interactions.

4.2 Rationale

In order to ensure that we achieve our learning outcomes, we have mapped aspects of the exhibit design to each outcome (Table 1). For example, in order to convey the learning outcome that computers use knowledge representations to store information about the world, we have allowed users to create and modify characters by modifying a semantic network.

5 IMPLEMENTATION

The exhibit is implemented for an Ideum table (Figure 5), which allows multiple users to interact with a digital display simultaneously via a large touchscreen as well as interactive tangible pucks. The interaction is developed using the Godot game engine.

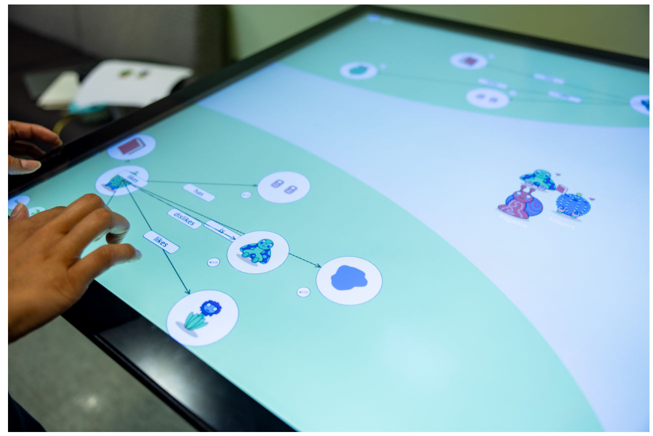

Figure 5: *Knowledge Net* on the Ideum table

Users are presented with four 3D-printed tangibles representing the four characters we have designed. Users can select one of the tangibles and place it on the designated spot at their station to assign that character to the station.

The station will automatically populate with a semantic network describing the character represented by the tangible, and a digital version of the character will appear in the center "world" of the table.

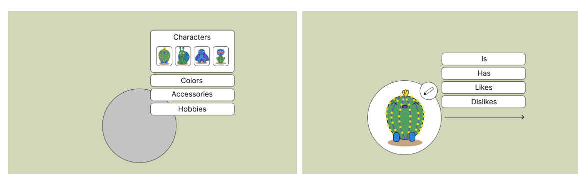

Figure 6: Drop-down menus

Learners can then modify the existing graph by adding or changing nodes, or they can clear the graph and create a new one. At each station, a user can tap on the screen to generate a new node. The node has a drop-down menu of possible features, and the user can tap on the one they want the node to represent (Figure 6, left).

The user can then tap on the node and drag in order to create an arrow leaving the node. A new node will also be generated once the arrow is dropped, and the user can select arrow and node labels from the drop-down menus (Figure 6, right).

The user can continue adding nodes and connections to develop their character. As the user modifies their graph, the corresponding character in the center "world" changes appearance and behavior according to the user input.

6 FUTURE WORK & IMPLICATIONS

Our design connects to the conference theme of "Organic Creative Spaces" as learners can use the semantic networks to craft the appearance and behaviors of the characters; thus the learners are creating an architecture from which character interactions organically emerge. Additionally, the terrarium theme of our digital "world" is inspired by the natural world, allowing users to create their own digital "ecosystem".

In future iterations of *Knowledge Net*, we plan to develop more complex character behaviors based on learner-generated semantic networks. This includes adding more possible node and arrow labels, and additionally developing the depth of the interactions between characters. By observing more complex outputs, we aim for users to think more deeply about their semantic networks as they try to identify the aspects of their networks that caused certain interactions. For example, given the networks in Figure 7, Filbert might hold a purple cupcake since Filbert likes baking and likes Bliff, who likes the color purple and cupcakes.

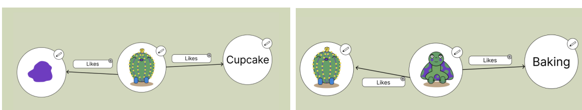

Figure 7: Possible network in a future iteration

Moreover, in order to further develop the creative making aspect of our design, we plan to incorporate a way for users to take home an artifact representing their character and the corresponding semantic network. This could take many forms, such as a printout of their created character and network or a video emailed to them of their character's interactions with other characters. We hypothesize that this artifact will help users remember the interaction and the concept of knowledge representations after leaving the museum; we also hypothesize that users will make a personal connection to the artifact, and correspondingly, to AI.

Our next steps include conducting a study of middle school age learners' interactions with the exhibit at the Museum of Science and Industry, Chicago. In the study, we will test the mapping between our design and learning objectives in order to ensure that our design choices lead to our desired learning outcomes. We will conduct this study using learning talk analysis [27] to examine practices of inquiry and engagement with learning objectives with dialogue, as well as personal meaning mapping [31] to explore visitors' personalized learning trajectories before vs. after interacting with the exhibit.

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