Sense-O-Nary: Exploring Children's Crossmodal Metaphors Through Playful Crossmodal Interactions

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(a) The circular box, which has 6 compartments, each containing one of the sensory objects.

(b) The sense spinner, has various senses used to describe objects.

(c) The selection box, contains all of the sensory objects that could be described.

Figure 1: During the Sense-O-Nary game, children in one team pick a sensory object from the circular box (b), spin the sense spinner to get a random sensory modality (c) then describe the sensory object through the given sensory modality. A second team then tries to guess the original sensory stimuli from the first team's metaphor from the selection box (a)

ABSTRACT

Metaphors enrich language by allowing us to express complex ideas through familiar concepts, enhancing both understanding and creativity in communication. Crossmodal metaphors are metaphors where one sensory modality is understood in terms of another (e.g, a sharp smell). Crossmodality is an integral part of how we make sense of and create meaning about the world. However, there is a lack of research on how children generate crossmodal metaphors and the interpretation of such metaphors. We present Sense-O-Nary, a game we designed to explore how children react when asked to create crossmodal metaphors in a novel environment. Children are presented with one sensory input and then asked to describe it using a different sense, for another team to guess what the original sensory input is. We engaged children (n=65, aged 8-10) to play this crossmodal metaphor generation game. We qualitatively analysed children's exchange of crossmodal metaphors to define a set of crossmodal association strategies and then use this to categorise the metaphors they created. We discuss how engaging with crossmodal metaphors can enhance children's linguistic development and how our findings can inform the design of interactions that involve multiple senses.

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CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI); Empirical studies in HCI**.

KEYWORDS

Crossmodal Metaphors, Multisensory Interactions, Children Interaction

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1 INTRODUCTION

From an early age, children learn to add meaning to their experiences through metaphors. Metaphors are language tools that compare two seemingly unrelated concepts by highlighting similarities to convey a particular idea, image, or meaning [14]. Learning how to create metaphors typically occurs through exposure to language in context, where individuals gradually understand the abstract connections between seemingly unrelated concepts, guided by cultural, linguistic, cognitive and physical/embodied development [45].

Prior work on metaphor development in children greatly focuses on the stages in which children start to make metaphoric associations [44], the role of metaphor in cultural understanding [49], the role of embodied experiences in grounding abstract concepts through physical experiences (e.g., [33]), or the opportunities to support metaphor development through multimodal teaching and learning resources [36]. In contrast to prior work, in this paper, we focus on the role of crossmodal metaphor development in linguistic development and interactions. Crossmodal metaphors blend sensory experiences across different modalities, revealing the brain's synesthetic abilities and the interconnection of sensory processes [39].

We introduce Sense-O-Nary, a game that tasks children with the challenge of constructing crossmodal metaphors. Crossmodal metaphor development and correspondences is pivotal to various aspects of the intricate interplay between sensory modalities and metaphors in shaping emotions, interactions and experiences across domains (e.g., cognitive psychology (e.g., [41]), cognitive science (e.g., [35]), visual arts (e.g., [40]), and business applications (e.g., [34]).

Through an exploratory study with N=65 children, ages 8-10, we designed the Sense-O-Nary game and task to capture the metaphors children construct when tasked to perceive information gathered through one sensory input and map that experience to another sensory input. Thematic analysis of the 121 metaphors, revealed a set of association strategies children use in crossmodal metaphor construction (Familiarity, Geometric Features, Personal Connection, Sense of Pleasantness, Vocalisation, Association Coherence, and Overriding the Rules). Association strategies pertain to the non-arbitrary perceptual mapping (correspondences) of stimulus features both within and across senses [23, 31]. Based on these findings, we discuss children's use of association strategies during crossmodal metaphor development. We also share insights for the design of multisensory games, for crossmodal language development, cultural understanding, and in-depth inquiry through the senses.

2 BACKGROUND

2.1 Metaphors, Children, and Cognitive Development

The study of metaphor reveals how metaphors influence human cognition, communication, and world perception. Prominent scholars in cognitive linguistics and literary analysis assert that metaphors are fundamental to human thought, shaping how we understand the world and interact with it [14, 22]. Exploring the rich diversity of metaphors across cultures highlights both their universal nature and cultural nuances [8]. Moreover, the significance of metaphors is underscored by their crucial role in political discourse (e.g., [32]), machine learning (e.g., [11]), and interaction design (e.g., [28]). Metaphor comprehension in children is vital for cognitive and linguistic growth [44, 48]. Vosniadou et al. [44] emphasise the interconnectedness of metaphor comprehension with broader abstract thinking development in children, linguistic skill development and cognitive maturation. Winner et al. [48] addresses the developmental trajectory of children's metaphor comprehension; children typically grasp simple metaphors around age two with a rudimentary understanding that evolves into greater sophistication as cognitive development progresses. By ages seven to ten, children exhibit the cognitive capacity for complex metaphors, highlighting the gradual, age-dependent nature of metaphorical understanding. Mastering metaphors entails children's ability to recognise, interpret, and employ figurative language, a skill set fundamental for abstract thinking, creativity, language proficiency, computer programming and beyond [38, 44, 48].

Metaphors are powerful pedagogical tools in teacher education [26], instructional design [47], and for evidencing students' learning [46]. Research on interaction design and children (IDC) has drawn on the significance of metaphors in proposing applications and devices (e.g., [4, 20]) that support student learning and understanding of a concept. Across this work, tangible and embodied interaction techniques are commonly employed [4], which is supported by mounting evidence that "Metaphors are embodied, otherwise they would not be metaphors" [42] and mounting evidence that learning requires embodied activity [27].

2.2 Crossmodal Interactions and Metaphors

A growing trend in interactive system design is to draw on crossmodality. Crossmodal interaction refers to the integration and interaction of different modalities when information is transferred between the senses [23]. Foundational to crossmodal research, Uznadze [43] and Kohler [21], established the "Bouba-Kiki" effect based on participants correlating nonsensical words with visual features and identified four factors influencing this seemingly non-arbitrary visio-linguisitc correspondences. Subsequent studies of the "Bouba-Kiki" effect involved diverse participants, including children [29], and global populations [6], and confirmed that people universally associate round shapes with "Bouba" and sharp shapes with "Kiki." Additionally, Bouba is generally linked to positive emotions, while Kiki is associated with negative. Another important crossmodal phenomenon is the McGurk effect [30], which pertains to the interaction between auditory and visual perception in speech perception. Here, participants are presented with a video where an individual utters ta syllable (e.g., "ga"), paired with a video of the individual uttering another syllable (e.g., "ba"). Many participants tend to report perceiving a combination syllable (e.g., "da"), indicating that visual information influences auditory perception.

More recently, the study of crossmodal interaction has investigated correspondences between active haptic experiences of 3D objects, colour and emotion using "Bouba/Kiki" [23] and found that there were connections between high degrees of complexity and angularity with red, low brightness and high arousal levels. Less complex round shapes were associated with blue colours, high brightness and positive valence levels. They created a design space for creating tangible multisensory artefacts that can trigger specific emotional precepts. Another paper investigates how children associate emotions with scents and 3D shapes [31]. They found that there were associations between the combination of angular shapes ("Kiki") and lemon scent with arousing emotion, and of round shapes ("Bouba") and vanilla scent with calming emotion. The exploration of crossmodal metaphors and interactions thus represents a significant and promising area of research in the development of educational technologies. However, little research has engaged with crossmodality and metaphor construction, particularly for children. Our work builds on the previous work [23, 31] by using the associations strategies they created, using them with a younger audience and then finding if there are any others that are specific for young children. Cacciari et al. [7] discuss how specific senses react with one another in metaphor; They found that some senses, like taste and colour, do not interact or have easily created metaphors between one another. In this paper, we introduce a tangible crossmodal game that gauges children's crossmodal metaphor construction through playful interactions.

3 STUDY

This study explores the crossmodal metaphors children utilise when describing sensory experiences through a different sense (e.g. using smell to describe taste). Toward this aim, we designed the Sense-O-Nary game that tasks children with describing specific sensory experiences through another chosen sense. In this section, we present the design of Sense-O-Nary, our implementation procedure with N=65 students, the data collected, and our approach to analysis.

3.1 Sense-O-Nary Box Design

The Sense-O-Nary game consists of three parts: a circular box, a rectangular box and a sense spinner (Figure 1). The circular box consists of 6 hinged compartments, each with a specific sensory object inside that is either touched, smelt or seen. The lid has a spinner mounted atop to allow for the random selection of a compartment during the game. The sense spinner consists of 6 sections, one representing each sense, and, given the strong connection between sensory modalities and emotion [23, 31], we added one option for emotion. The spinner is used to determine which sense the children have to describe their sensory experience through. The rectangular box consists of 12 open compartments, one for each possible sensory object used in the two circular boxes. The rectangular box is used as a reference throughout the game to allow other children to choose the object they believe aligns with the description.

3.1.1 *Sensory Objects.*

The sensory objects found inside the boxes consist of 3D printed shapes for touch, colourful laser-cut acrylic for sight, and small jars of cotton balls saturated with essential oils for smell. The choice of sensory objects is based on previous crossmodal associations between shapes, smells and colours and the visio-linguistic crossmodal correspondence phenomena "bouba" and "kiki" [43]. Based on previous research, we included sensory objects that were strongly associated with either "bouba" or "kiki" and also more neutral objects that did not have a strong association with either or had not previously been researched [17, 23, 31]. The chosen sensory items are shown in Table 1.

3.2 Participants

N=65 children, aged 8 to 11, volunteered for this study. [1] Children were recruited via University sponsored events where multiple researchers work with groups of children in schools/labs on a variety of studies. These events are organised in conjunction with local schools. The schools directly handled the consent forms and children attended the events anonymously with no personal data being shared with the University. Only children who gave consent to the school were able to attend.

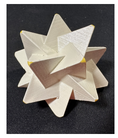
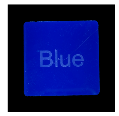
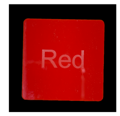
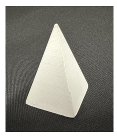
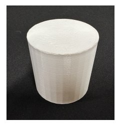
3.3 Procedure

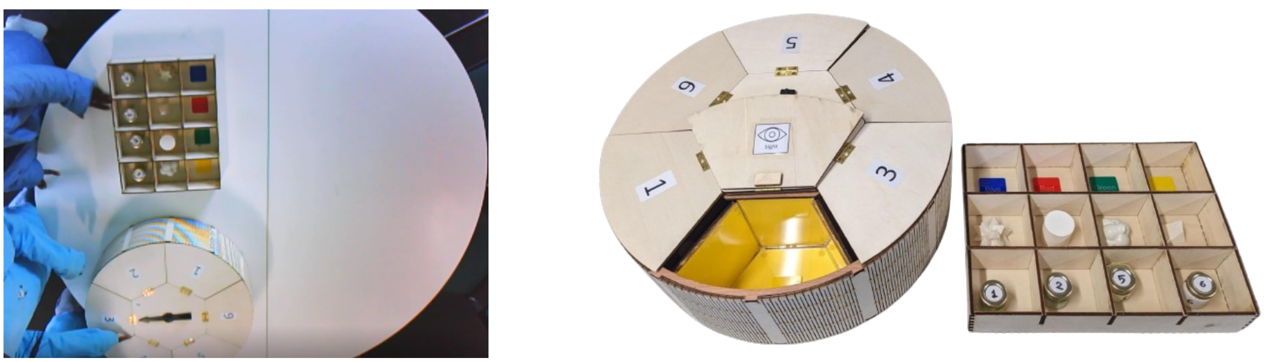
The study was conducted in a University where groups of 6 to 8 children, who knew each other, visited the university lab for 20 minutes each to play Sense-O-Nary. Group members were prearranged by the teachers and in this activity, groups split into two teams by mutual agreement. In total, 18 groups played (N=65); five groups on Day 1, three groups on Day 2, 3, and 4 each, and four groups on Day 5. To prepare each participant group, two researchers introduced the game activity and provided the groups with an example of how the game should be played by playing a round themselves. Researchers remained present throughout the game to guide the children through the task if they experienced any difficulties.

The Sense-O-Nary game design is loosely based on the design of "Pictionary," where players draw various prompts and other members of the team have to guess the original. Instead, for Sense-O-Nary children had to describe a sensory experience through another sense (or as an emotion) for the other team to guess. Firstly, the six to eight children in a participating group were split into two teams who stood facing one another, about 6m apart, in a lab with tables. Each team was given a circular box and a rectangular box which they placed on the table in front of them; see fig 2b. One sense spinner was shared between the two teams and was passed between the teams by the facilitating researcher as each took their turn. Members from team 1, spun the spinner on top of the circular box and opened the compartment to experience the sensory object inside. The same children then spun the sense spinner to determine which sense they had to use to describe the sensory experience. Then, the team members quietly discussed their answer before sharing it with team 2. The children in team 2 then had to guess which original item from the rectangular box team 1 were describing, giving a description, if they could, of why they

[1] We are unable to provide any demographics, as the data collected was fully anonymous.

Table 1: Table displaying the chosen sensory items and their correspondence to Bouba or Kiki. Crossmodal correspondences formed part of the decision of what objects we used.

Sense	**Touch**		**Sight**		**Scent**	
Item Name	Bouba	Kiki	Blue	Red	Vanilla	Lemon
Image						
Bouba/Kiki?	*Bouba*	*Kiki*	*Bouba*	*Kiki*	*Bouba*	*Kiki*
Item Name	Pyramid	Cylinder	Yellow	Green	Peppermint	Rose
Image						
Bouba/Kiki?	*Neutral*	*Neutral*	*Neutral*	*Neutral*	*Unknown*	*Neutral*



(a) A still image from one of the video recordings, showing how the game was set up

(b) The circular and rectangle box used in Sense-O-nary, with one compartment open with the visual stimuli "yellow".

Figure 2: Still images showing the Sense-O-nary box and how it was setup in our study

chose that particular item. The answer was then revealed to the other team. This then repeated, swapping the roles for each team, each round. We used a random spinner for both the compartment and the sense allocation, as it worked well with the playfulness of the game and reduced potential bias in the children [37]. However, this led to certain combinations that yielded no data (see Table 2 for allocations). For instance, "Bouba", the 3D-printed touch model, was never characterised as a smell. To address this issue in the future, we would conduct the game multiple times and enlist a larger number of participants.

3.4 Data Collection and Analysis

Each group was filmed using a GoPro camera, which recorded both audio and visual, resulting in 8 hours and 51 minutes of footage (with each session taking roughly 30 minutes). We manually transcribed audio from these recordings, including the debriefing and introductions. Subsequently, one researcher performed an initial content analysis [13] and isolated all instances when a participant described the first item they selected from the Sens-O-Nary game (e.g., the colour blue, the scent of vanilla, a pyramid shape etc), a second sensory element (e.g., smell, taste, emotion etc), and then the child's metaphor to describe the relationship (e.g., "smells like a medieval pipe", "sounds like cotton candy"). The original dataset included 121 data points. In some instances, children made errors in their descriptions, attributing the item to the sense most commonly associated with it rather than describing it through the sense chosen by the spinner. For example, a smell was described as a smell on two occasions, and a sight was described as a sight once. This data was removed from our data set. In addition, we removed any data that was incomplete or any instances where a teacher provided the child with suggestions to assist in the formulation of the metaphor. In total, 115 data points remained.

To analyse the data, we coded the six crossmodal association strategies based on previous research [23, 31] (see Table 3). As not all data aligned completely with these strategies, we created two additional association strategies: "Overriding the Rules" and "Vocalisation". For "Overriding the Rules", participants described a sense

Table 2: The number of times the item was described using a particular sense, the X shows the objects sense that it is naturally associated with, so the children should not describe an item by that particular sense.

Item	smell	sight	touch	taste	emotion	sound	total
Rose	X	1	1	3	2	4	11
Vanilla	X	2	4	4	2	3	15
Lemon	X	1	3	3	4	1	12
Peppermint	X	2	2	2	0	1	7
Green	2	X	9	3	0	3	17
Red	1	X	2	1	0	4	8
Yellow	1	X	0	0	1	1	3
Blue	0	X	4	0	4	3	11
Bouba	0	2	X	1	1	5	9
Cylinder	4	1	X	0	0	0	5
Kiki	3	1	X	5	1	1	11
Pyramid	0	0	X	4	1	1	6
Total	11	10	25	26	16	27	115

Table 3: Descriptions of crossmodal Association Strategies, six of these are from prior work, and the two in bold are original in our findings

Strategy	**Description**
Familiar	A description was created by relating the item to a commonly seen object, emotion, texture etc
Geometric Features	Geometric features have been used to describe the item, these features can be imagined or part of the object.
Association Coherence	A prior description for a different object is used for the new item due to them evoking. a similar reaction
Personal Connection	They use a specific, personal story that reminds them of the item to describe the item.
Sense of Pleasantness	Positive and/or negative words are used to create a description.
Vocalisation	A sound/noise is made instead of using words to describe an item.
Overriding the Rules	Words from a different sense have been used to describe the item.
Location	Associations were made on the basis of links to actual or imagined places.

using a sense other than the one they were assigned. "Vocalisation" was used when participants made a noise or sound instead of using words to describe their metaphor. "Location", an association strategy that was found in previous work [23, 31], was removed as we found no instances of this strategy. There were no instances where multiple different association strategies were being used.

4 FINDINGS

Here we present the results of analysing 115 metaphors created by N=65 children through the use of Sense-O-Nary. We chose to assign each metaphor to only one association strategy for this study, as it means the association strategies are clear and concise. We begin by highlighting the frequency of association strategies used by the children when creating the crossmodal metaphors. This revealed how children integrate and abstract different sensory experiences, allowing for insight into the cognitive processes of children. The more prevalent association strategies can then be used in design activities related to multisensory integration. During the study, there were 16 instances where the children did not give a reason for why they chose that particular metaphor and four instances where they were not sure why they described the item using that metaphor. Multiple children used the same metaphor for 3 specific sensory objects. The colour green was related to "grass" on four separate occasions, vanilla was related to "ice cream" five times, and blue was related to "water" or "sea" six times. However, all other metaphors were only used once for their respective item. Finally, we describe the crossmodal association strategies that participants used when constructing their metaphors for a given sensory modality.

4.1 Distribution of Association Strategies

Children in this study were less likely to the following association strategies when describing a given sense: "Association Coherence", "Personal Connection" or "Sense of Pleasantness". Instead, the participants most frequently used the "Familiarity" association strategy. Table 4 provides an overview of these findings; below we provide additional details.

4.1.1 Most Used Strategies. The data presented in Figure 3 demonstrates that the children predominantly favoured the "Familiarity strategy". Application of this strategy suggests that the children related the sensory item to a prior reference. This strategy was first introduced as "Everyday Object" in previous work [31]; we adapted

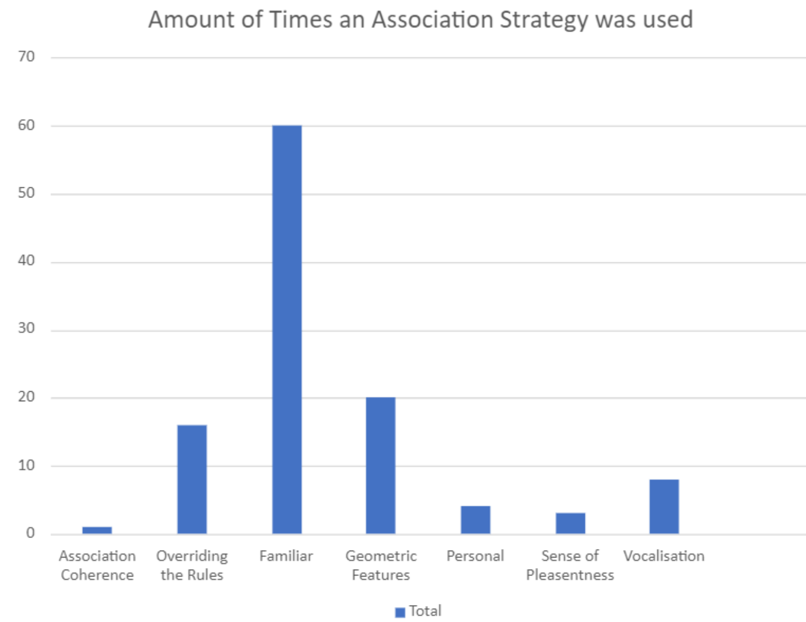


Figure 3: A bar chart showing the frequency of each association strategy used.

this strategy to more expansively cover familiar experiences–beyond interactions with objects to include familiar smells, textures, etc. rather than just objects–as this type of association.

In the study, children used familiar items in their descriptions the majority of the time. With it being used for emotion 47.06% of the time, sight 40%, smell 90.91%, sound 52.00% and taste, 62.50%. Additionally, it was used 53.57% of the time, regardless of what sense was being used to describe. We expect that this is because it is the easiest way for children to try and connect with their peers. [18]. We attribute the dominant use of this association strategy to the low cognitive load and accessibility of drawing on that which we encounter regularly. Moreover, children typically develop their understanding of the world though embodied experiences and so they may form connections between sensory modalities based on shared or linked experiences [3, 5, 10]. Children may also use familiar items to describe sensory experiences due to a still developing vocabulary, as they provide tangible areal references that are easier for them to express and understand. [2, 16].

4.1.2 Least Used Strategies . The least used strategies, regardless of which sense were being used, were "Association Coherence" being used 0.89% of the time, "Personal Connection" being used 3.57% and "Sense of pleasantness" being used 2.68% of the time. One of the key differences with our findings compared to previous research [31] [23] is that we had a very limited amount of metaphors created using these association strategies. We believe that this is because there is a difference because of the age ranges. Associative coherence often involves more advanced cognitive processes. Young children's cognitive abilities, including memory and language skills, are still developing, and so they may not be as adept at making these kinds of connections. Personal connections are based on life experiences and as young children have not accumulated enough of a varied experience then they may not form these strong personal connections with items that older peers may be able to create. Additionally, if the children are still in the early stages of linguistic development then they may focus more on basic communication and so they may not fully engage in expressing personal connections through their language. This was a significant motivator for us to develop this game, we wanted to contribute to children's development of metaphors. Exploring how a child's association strategies and the metaphors that are created, change and develop over time could be intriguing.

4.2 Crossmodal Association Strategies by Primary Sensory Experience with Sense-O-Nary

Crossmodal association strategies that participants used to construct metaphors between sensory modalities provide insight into how modal inputs can support cognitive processes through other sensory modalities. Figure 4 and the findings below situate the metaphors developed during the crossmodal interactions that occurred when playing with Sense-O-Nary.

4.2.1 Sight. When describing what an item looked like, the majority of the time the children used the "Familiarity" strategy, with 40% of the metaphors using this association strategy. One participant, for instance, described the peppermint smell as looking like *"candy canes at Christmas"*. Another participant stated that the cylinder shape *"look[ed] like a mug"*. The next most common strategy that occurred involved children "Overriding the Rules." This only occurred in instances where the children were given a scent to describe by sight. In each of these instances, the children instead used taste as

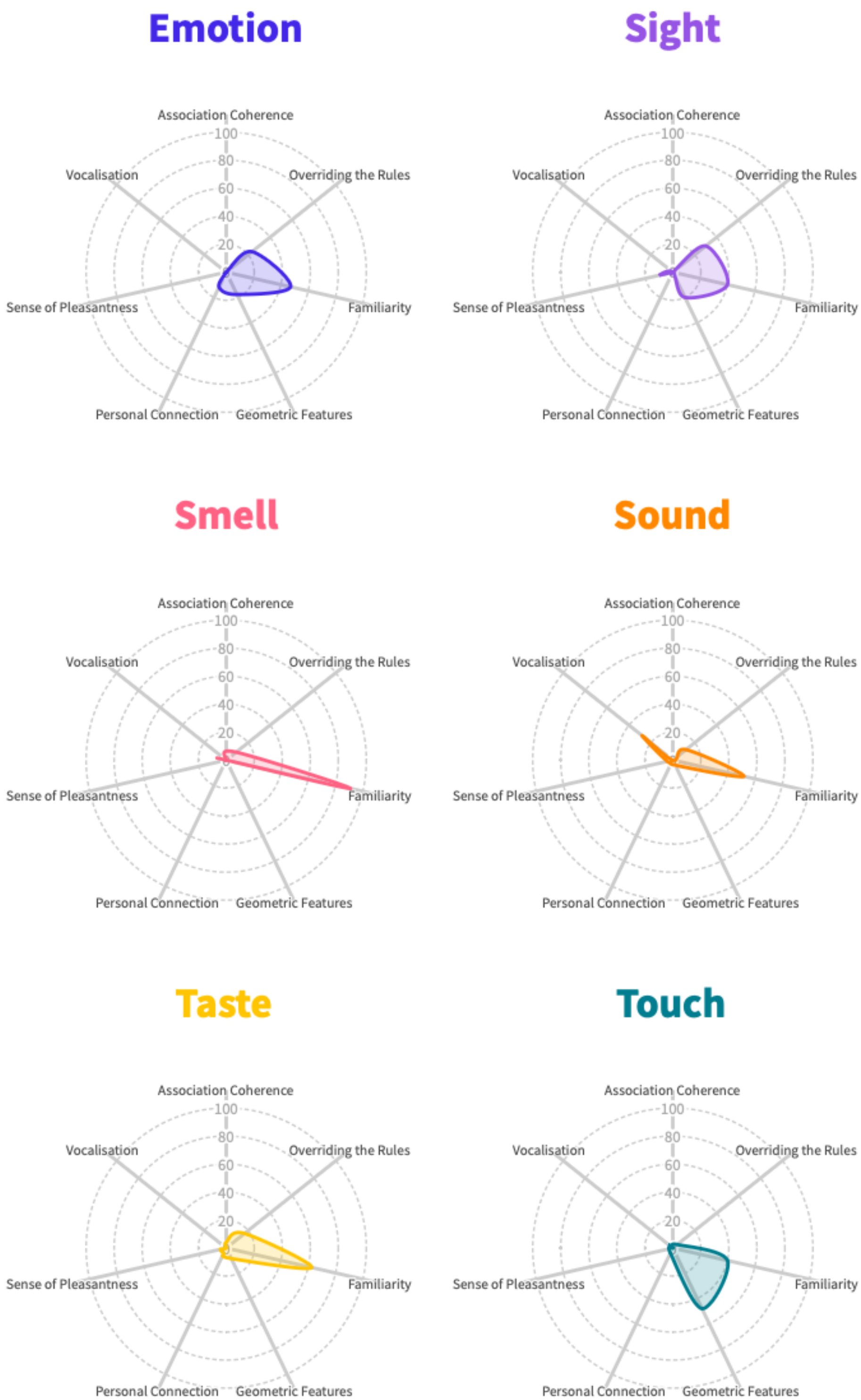


Figure 4: The frequency of the association strategies used for the particular primary sensory modality.

Table 4: Percentage Distribution of Association Strategy by Sense

	Association Coherence	Overriding the Rules	Familiarity	Geometric Features	Personal Connection	Sense of Pleasantness	Vocalisation
Emotion	0.00%	23.53%	47.06%	17.65%	11.76%	0.00%	0.00%
Sight	0.00%	30.00%	40.00%	20.00%	0.00%	10.00%	0.00%
Smell	0.00%	9.09%	90.91%	0.00%	0.00%	0.00%	0.00%
Sound	0.00%	12.00%	52.00%	4.00%	0.00%	4.00%	28.00%
Taste	4.17%	16.67%	62.50%	8.33%	4.17%	4.17%	0.00%
Touch	0.00%	4.00%	40.00%	48.00%	4.00%	0.00%	4.00%

their descriptor. For example, one participant described the scent of lemons as tasting like *"orange juice after you've brushed your teeth"*.

4.2.2 Smell. With Smell "Familiarity" demonstrated the strongest correlation between strategy and sense, with it being used 90.91% of the time. Unlike with Sight, the participants were more descriptive with their answers. For example, one participant described the red colour as smelling *"like a rose"* while another described kiki as smelling like *"brick or stone"*. Finally one participant said that the colour yellow was *"like a banana smoothie"* and another said the colour green as *"freshly cut grass"*.

4.2.3 Sound. Sound had a relatively diverse distribution of strategies across the variety of sensory items provided. We expected the majority to use the "Vocalisation" strategy, however, only 28.00% of the time did participants create sounds to explain how they believed the item would sound. Examples of "Vocalisations" included *"sh sh sh sh"* to describe the colour green and *"Krrrrrr"* to describe peppermint. Similarly to Sight and Smell, "Familiarity" proved to be the most used strategy, having been utilised 52.00% of the time. Sound examples varied in depth of description, from highly specific, *"an orange being squished"* to more generic, *"windy"*, both for the smell of rose. The "bouba" shape was described as sounding *"like cotton candy", "like waves"* and as *"like sand falling down [...] reminds us of Egyptians"* by different participants.

4.2.4 Touch. While Touch had a similar diverse distribution of strategies to Sound, "Geometric" and "Familiarity" were the two dominant strategies children tended to use. "Geometric" was the most common strategy at 48.00%. The children used words such as *"spiky and smooth"* and *"fuzzy"* to describe the colour green and "smooth" to describe blue. Children described the smell of lemon as *"squishy soft"* and *"sticky"* while the smell of rose was described as *"spiky"*. "Familiarity" was the second most used strategy, being used 40.00% of the time, with instances including being reminded of *"grass"* when describing the colour green. One group described the scent of peppermint as *"toothpaste"*.

4.2.5 Taste. Of all the senses, Taste had the widest distribution of strategies, with all but "Vocalisation" being applied. One lesser-used strategy was "Association Coherence", with answers such as kiki *"tasting like a cactus ... and a bearded dragon"*. Another lesser-used strategy was "Overriding the Rules", with children describing the smell of rose as feeling *"soft, fragile and sharp"* and the pyramid being described as *"sharp around the edges."* Children always reverted to using touch to describe the sensory items when "Overriding the Rules." "Familiarity" was once again the most used association strategy, with it being used 62.50% of the time. Examples included the colour green tasting *"like sour candy"* and vanilla being described as tasting *"like melted ice cream"* or *"Dr Pepper out of a vending machine"*. Some more imaginative examples included the pyramid shape being described as a *"freshly baked wafer"*, as it reminded the children of an ice cream cone, and the bouba shape, which children described as *"the fluffiest puffiest marshmallows"*.

4.2.6 Emotion. When devising a description of an item using Emotion, the majority of the time the "Familiarity" strategy was used, with it being used 47.06% of the time. Examples mainly included the children saying a single word to describe the emotion like *"happy"* being used for bouba, *"sad"* or *"relaxing"* to describe blue and rose being described as *"love"*. Using "Overriding the Rules" was the second most common strategy used to describe Emotions, making up 23.53% of instances. For example, one participant described the vanilla smell as tasting *"like ice cream"* and another described the Kiki shape as looking like *"an urchin washed up on the beach"*. The "Vocalisation" strategy was used once, where the pyramid was described as *"OW."*

5 DISCUSSION

We set out to design a game to engage children in metaphor development based on one sensory experience and making an association through another sense. Through N=65 students' engagement in this game, we analysed 115 unique data points to find that "Sense-O-Nary" supports and encourages crossmodal metaphor generation. We present findings on the frequency in which the participants used eight different crossmodal association strategies in the formation of their metaphors, as well as the association between a sensory input and the association strategies used to make sense of that input through language when experiencing the secondary sensory input.

5.1 Crossmodal Associations Used and Not Used

Comparing our findings to prior work, six of the eight association strategies (Everyday objects–i.e., Familiarity, Geometric Features, Personal Connection, Sense of Pleasantness, Vocalisation, Association Coherence, Overriding the Rules and Location) were consistent with previous work on crossmodal correspondences [23, 31]. The additional two association strategies discovered through our findings include: Vocalisation and Overriding the Rules.

Our findings indicated that "Vocalisation" and "Overriding the Rules," strategies used by participants in our study, contrasted with patterns seen in earlier studies (e.g., [1, 31]). "Vocalisation" involved children using sounds as metaphors instead of words, such as a child describing peppermint with a sound akin to "Krrrrr". The strategy "Overriding the Rules" was characterised by children describing items using senses other than the one assigned, exemplified by a child using the sense of touch to describe the taste of a pyramid as "sharp around the edges". We attribute this to the fact that children in our study were 8-10 years old whereas the previous research used participants aged 10-17 years [31] and 22-37 years [23]. Older participants may be more linguistically developed.

All the while, there was no use of the "Location" association strategy, which was prominent in [23, 31]. This strategy, where participants create metaphors based on real or imaginary places, was not found in the younger age group, possibly due to their less developed memory skills and a lower likelihood of them assuming their peers would understand place-based metaphors [16]. These observations confer our conjecture that age is an important factor in determining which association strategies are used.

5.2 Insights into designing playful technology for embodied and cross-sensory learning

5.2.1 Designing Educational Technologies. The main reason why we created Sense-O-nary was that children struggle with creating crossmodal metaphors, be that due to a limited vocabulary, limited experiences or a lack of exposure to metaphorical language. To teach children about different types of crossmodal metaphors, and improve their linguistic development, future work may build on the association strategy "familiarity" and use it to push and expand the types of association strategies that the children use to create their crossmodal metaphors. It may be positive to focus on increasing the amount of association strategies used by asking questions like "what memory makes you think of this item?" or "is this a positive or negative object? " creating multiple connections and multiple ways of creating the crossmodal metaphors, allowing for deeper connections to be made that don't rely on one type of association strategy. This is where the design space that we created can be used to see the association strategies that were not used as much with a certain sense, so they can be focused on to create more connections.

Educational technology can greatly benefit by using various association strategies. These strategies can increase the retention of taught material by establishing multiple pathways and connections, thus improving recall [15]. Personalised learning can also be facilitated, acknowledging that individuals learn differently, strategies such as personal connections and location enable learners to develop their own unique methods for comprehending information [25]. The use of association strategies will also allow for more accessible learning, as those with sensory impairments or learning disabilities can be shown multiple different ways of creating a connection, allowing them to find a connection that suits their needs.

5.2.2 Playful Design. Playful design is very important and beneficial when creating technology for embedded and cross-sensory learning. It kept the children engaged and motivated when creating the metaphors. Play is a natural way for children to learn [12] and encourages self-directed exploration, leading to a deeper and more meaningful understanding of the metaphors created. It also allowed for a reduced fear of failure in the children as they were able to explore and create the metaphors without being told that they were incorrect, meaning we were able to gather all the metaphors that the children shared gaining a better understanding of what methods they actually used. Our playful design also allowed for embodiment to be used, as children had the freedom to move explore and investigate the objects with their whole body.

5.2.3 Embodied metaphors. Embodied metaphors were one of the main reasons for why we created the box in the way that we did, as embodied metaphors in tangible user interfaces (TUIs), take abstract concepts and anchor them in the physical world, making them more accessible and understandable for young learners. Lindgren [24] demonstrates the benefits of body-based metaphors in a mixed-reality environment, showing that they can lead to a deeper understanding of the learning domain. These metaphors are not just visual but also tactile, engaging multiple senses and reinforcing learning through physical interaction. By manipulating these physical objects, children are not merely learning about the concepts but are experiencing them in a way that is grounded in their physical reality. This multisensory approach aligns with kinesthetic learning theories, suggesting that physical engagement can significantly enhance comprehension and retention, especially in complex subjects. In this way, embodied metaphors in TUIs become powerful tools for bridging the gap between abstract academic concepts and the tangible world of children's everyday experiences. While expanding the research of sensory modalities in tangible interaction and metaphor construction is useful, there remains a gap in understanding how these modalities interact and influence one another. Examining how children express crossmodal metaphors through their body language and movements could be crucial in fully understanding the crossmodal metaphors that are created. When creating technology for cross-sensory learning using embodied metaphors is vital to create a space that is inclusive and supports the understanding of young people.

5.2.4 Diversity and Inclusive Design. Using cross-sensory metaphors has the potential to provide support for individuals who are blind, deaf, or struggle with the use of a specific sense, by assisting individuals in comprehending a sense that they may not be able to use; for instance, someone who is blind might gain a deeper insight into colour and be able to explore colours without the use of sight, for example through sensory substitution devices [9, 19]. Establishing these connections may contribute to forming a more comprehensive understanding of an experience that they would otherwise may be unable to experience and potentially improve the design of such devices.

5.2.5 Limitations. One issue we found with our design of Sense-O-nary was that children were competitive, despite our best efforts to emphasise that there were no winners or losers of the game. This may have meant that they created metaphors that their peers would not understand, so that the other team would guess the item "incorrectly", resulting in metaphors that did relate to the object, but the other children did not guess correctly. This was part of the reason why we did not analyse if the guesses were correct or incorrect. Such limitation may perhaps be best addressed through more controlled studies of crossmodal metaphor generation.

6 CONCLUSION

We presented a game, Sense-o-nary, which was designed to allow the exploration of crossmodal metaphors in children. This game provides a novel and new way to look at how different senses interact with one another and the types of metaphors that can occur when a child is given the freedom to explore. We created a set of association types to classify how these crossmodal metaphors were created and used this to create a design space. This design space can be used to highlight the strategies that are not being used for a particular sense, so that future devices can focus on getting the children to create metaphors using these strategies. Allowing for better embodied learning to occur and for children's language skills to develop. Our study focuses on children, as children have more difficulty creating metaphors than older participants since their cognitive and association skills are still in development. Designing with playfulness in mind is important as it effectively maintains children's engagement and motivation throughout the whole study. Age is a very important factor when designing crossmodal metaphors as how an individual's senses interact changes depending on their age and their language comprehension.

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7 SELECTION AND PARTICIPATION OF CHILDREN

Children in this study were from five schools that had previously worked with two of the authors of this paper. The children were selected by the teachers and consent was gained from parents. This activity was one of several that children attended on the day. When children arrived at the university they were given housekeeping information and had data and research explained to them and were told that they did not have to hand in anything in any of the activities. Groups for the activities were formed by the teachers; no children's names were taken, ages were not recorded and anything that was handed in was given with consent and the child's assent.

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