

Article

Documenting Children's Spatial Reasoning through Art: A Case Study on Play-Based STEAM Education

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Abstract: The purpose of this paper is to examine how children's art can document emergent sensemaking of spatial reasoning. Spatial reasoning is the understanding of how both people and objects interact with, and relate to, one another. The recent literature has argued for spatial reasoning to be part of multiple domains in STEAM education by highlighting the dynamic nature of spatial thinking relevant in everyday life. The data come from a larger participatory design-based research project that incorporated play, environmental education, and embodiment in a STEAM curriculum. The paper analyzed art created by a focal group of children (6–8 years) as they learned about the kelp forest ecosystem over time. Findings reveal that spatial reasoning is not only an inseparable part of sensemaking in STEAM education, but has implications for environmental education in the elementary curriculum.

Keywords: spatial reasoning; STEAM education; play; environmental education



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1. Introduction

Over the last few years, there has been a push for the teaching and learning of spatial reasoning in K-12 classrooms. Spatial reasoning, or spatial thinking, relates to how objects and shapes organize, interact, move, and relate to one another [1,2]. What makes spatial reasoning unique is that it requires us to critically think about the concept of space. It asks us to consider how the objects and shapes that make up the world are organized in different ways [3]. The field of mathematics education often utilizes spatial thinking to develop geometric language and knowledge of shapes [4]. However, as science, technology, engineering, arts, and mathematics (STEAM) education [5] has gained attention and traction in education, many scholars have argued that spatial reasoning is visible in these other disciplines [6,7]. Not only does this include the situated practices of spatial reasoning in disciplinary work, but it also has visibility in everyday activities such as navigating, reading maps, or parallel parking.

What is most exciting about this perspective on spatial reasoning is how educators and researchers can design and examine spatial thinking as part of multiple domains, including environmental education. Expanding spatial reasoning toward a dynamic and critical way of understanding space inherently includes understanding the interactions and relationships between humans and the natural world. One of the implications of this study addresses the need for designing and implementing environmental education that fosters awareness of environmental issues for a sustainable future. The paper examines children's art as part of sensemaking spatial reasoning in a STEAM curriculum, as they learn about the kelp forest ecosystem and how humans impact the ocean in harmful ways. Therefore, the question that guides my analysis is: how can children's art document and illustrate sensemaking of spatial reasoning in STEAM education?

1.1. Spatial Reasoning in Elementary Education

Spatial reasoning is the understanding of objects' locations, movements, and relationships in space [3]. It considers how we navigate through the world, mentally transform

and envision images, and create representations [1,2]. Spatial reasoning also helps us to recognize how both static and dynamic objects are organized in space. For instance, we can imagine how different a rectangle would look if we folded it horizontally versus diagonally. When we define and think of spatial reasoning in this way, it fits well with geometric thinking, because it requires us to know how to build and mentally manipulate and transform shapes and objects. As a result, math educators and researchers often position spatial reasoning as a way to learn and identify shapes as both two- and three-dimensional objects (e.g., circles, cylinders, triangles, pyramids). These shapes can then be characterized in ways that geometrically define and describe them [8–11]. For example, a square has four straight lines and four equal internal angles, while triangles are made up of three sides and three angles.

However, spatial reasoning is more than the ability to mentally transform, decompose, and recompose shapes [12,13]. Spatial reasoning also requires us to examine these objects as they move in space [3,13,14]—how they look when they are rotated, how parts of objects can fit together, how locations of objects relate to one another, and how they are viewed from different perspectives and angles. These dynamic ways of utilizing spatial reasoning skills not only help us to orientate in space, but help us to understand the interactions and relationships between objects and people in our geometric world [3]. They ask us to understand the diversity of interactions, relationships, and dynamic movements between structures, aligning well with STEAM education [2,15].

1.2. Spatial Reasoning as Dynamic and Embodied STEAM Sensemaking

While spatial reasoning has historically been taken up in mathematics education, there has been a growth in the literature that advocates that spatial reasoning is “in domains that are not, on the surface, obviously spatial” [4] (p. 102). Many scholars have identified spatial reasoning skills, such as perspective-taking and scaling, which are closely tied to everyday practices and professions outside of mathematics [7,14,15]. A notable example of the importance of understanding shapes, size, and orientation was when German scientist Alfred Wegener proposed the continental drift theory by observing how the coastlines of South America and Africa fit together into a supercontinent [16]. There are several more examples of how scientific fields utilize spatial thinking; surgeons visualize areas in the body to plan for a surgical procedure, chemists can use three-dimensional models and illustrations to visually represent molecular structures, and geoscientists not only study other people’s maps and visualizations, but need to recognize and classify shapes and objects in their work [17].

When we think of spatial reasoning in this way, it becomes visible and meaningful in everyday life, existing in a variety of moving figures and objects that make up our geometric world [7,18]. Whether we are aware of it or not, we are constantly making sense of the space around us; from fitting a car seat into vehicles, assembling furniture, planting gardens, and navigating to places [3]. Spatial reasoning is “integral to everyday life. People, natural objects, human-made objects, and human-made structures exist somewhere in space, and the interactions of people and things must be understood in terms of locations, distances, directions, shapes, and patterns” [3] (p. 5).

Thus, not only is spatial thinking about understanding the dynamic interactions between human-made objects and structures, but interactions within nature, and between the human-made and natural world. These dynamic ways of understanding spatial relationships between people and nature not only have potential in STEAM learning, but can also address the need for climate literacy and environmental education [19]. Understanding the patterns of human and natural relations can help us understand environmental issues and how we impact or cause these problems [20]. Therefore, spatial reasoning is not only about being aware of space, but it requires us to consider how we utilize space, impact space, and inform the decisions we make while interacting in both the human and natural world [3,7,21].

As part of recognizing the dynamic nature of spatial reasoning, scholars have argued that spatial thinking instinctively requires the body as an essential tool for understanding spatial organizations and movements [22]. Several studies have already showcased the integral and interwoven relationship between gestures and mathematics [23,24] and have found that learners produce gestures to communicate understanding and meaning [7,22,25]. In science education research, we continue to see the inseparability of learning from the body and multimodal resources such as affect or emotions [26,27]. One of the commonalities across these studies is the iterative and reflective process of embodiment as we think aloud and learn [7,28]. These studies have shown how the body can become a sense-making resource to experience, question, and reflect on the interactions that make up our world [27,28]. Embodiment is not a static resource, but an everchanging and dynamic part of sensemaking. This body of literature encourages educators and researchers to consider the embodied nature of spatial reasoning, and how these dynamic sensemaking experiences are part of the process of understanding our moving world [29,30].

1.3. Children's Art as Act and Artifact of Spatial Reasoning

Drawing has been one of the most common school activities in elementary education, with children's artwork frequently displayed on classroom walls [31,32]. The research on children's drawings has not only found art essential in developing fine motor skills, creativity, expressing emotions, and storytelling [33,34], but as a method for assessing development and spatial skills [35]. However, in recent years, several scholars have warned educators and researchers of the danger of examining children's drawings as isolated assessment tasks, because it can lead us to focus on what children cannot developmentally do, instead of understanding what they can do [29,36]. Children's drawings, even in early scribbles, are a way for children to think through and communicate what they know about the world [35,37].

Modern research into mathematics furthers this notion, as scholars have embraced embodied approaches to learning, "drawing is not a matter of confirming an external world by fixing it and statically representing it, but a process of 'thinking' a world by making information available as part of and through a specific human perceptual experience in the process of becoming" [32] (p. 468). Thom & McGarvey [32] argue that children's drawings are not only an *artifact* that reveals spatial knowledge, but are an *act* or a way of sensemaking as children actively explore and wrestle with early geometric thinking. Their analysis of children's drawings over time [32] demonstrates the woven nature of embodiment, art, and spatial reasoning.

The goal of this paper is to bring together these perspectives of spatial reasoning by examining children's art as a part of sensemaking in STEAM education. I build on the argument that spatial reasoning is visible in the moving objects and shapes that make up our world, and ask how children's art can document these dynamic ways of spatial thinking. I also attend to children's art as both act and artifact by examining how children utilize spatial reasoning in their artwork over time.

2. Materials and Methods

This study is a participatory design-based research project [38] that brings together the expertise of three participating teachers and myself, a university researcher. We practice participatory design-based research because we believe in the importance of bridging research and practice in sustainable and meaningful ways. Through our collaboration, and the shared ownership of our study, our findings are not only shared with the larger community of scholars, but have direct implications for teachers' practice and pedagogies. The study site was in a West Coast city in the United States in a mixed-age classroom of 1st and 2nd grade students (6–8 years) at a progressive elementary school. Throughout the study, the three participating teachers and I shared the roles of both teachers and researchers; I, myself, often co-taught with teachers, while teachers often co-designed

measures and collected data. Our collaborative endeavor in researching, designing, and examining play and STEAM learning as part of environmental education continues today.

2.1. Study Design: Investigating the Kelp Forest

The data presented in this paper are from a larger study co-designed by myself and three participating teachers. The overarching goal of our study was to design and implement a STEAM curriculum that incorporated embodied play and environmental education. Together, we implemented a unit of inquiry investigating the interdependent relationships of the kelp forest and the human impact on these delicate and complex ecosystems. We also investigated the size and shape of kelp forest creatures to comparatively understand the different measurements, from microscopic plankton to kelp that can grow as tall as 100–175 feet. As the name suggests, kelp is a fast-growing alga that reaches the top of the ocean water and grows as densely as land forests. Kelp forests grow along the West Coast of North America and are home to a diversity of ocean species such as sea otters and urchins.

The larger study took place across four months and included activities such as costume-making, playing, collage-making, and pamphlet-making. As a central part of our design, children played as kelp forest sea creatures and engaged in embodied sensemaking on spatial thinking and ecosystems. By taking on these roles, students learned about the structure and function of marine creatures, their adaptations, and how each marine creature interacted with other species. Each child chose a sea creature that lives in the kelp forest, researched it, and created a costume to wear during play activities.

Children wore their costume and role-played as these marine creatures by moving and organizing themselves in ways that represented how they would interact in the kelp forest (Figure 1). For example, a child playing as a sea bass would “swim away” from children playing as larger predators. Similarly, children playing as sea urchins would pretend to “eat” children playing as kelp. The class also engaged in play activities that reflected on how different species move and how they compare to smaller or larger creatures. For example, in one play activity, children pretending to be kelp often proudly stated that, as they are so tall and dense, they can protect and hide fish from being hunted by orcas or sharks. Through embodied role play, children gained a critical understanding of the importance of each sea creature within the ecosystem, no matter how small or large they were.



Figure 1. Costumes for a sea urchin (left), and kelp (right).

As part of the wider STEAM curriculum, children also engaged in collage-making and pamphlet-making activities. The collages were created by children over the course of the curriculum to illustrate the kelp forest. Children worked on the same collage, editing and adding to their art over time as they learned more about the kelp forest ecosystem. The

children in the classroom were divided into five groups and were provided with various art materials (markers, colored paper, colored pencils, scissors, and glue). The collages were created on large poster paper that remained hanging on the classroom walls until the end of the school year. Over the three collage-making activity sessions, the same group of children worked on the same collage as they modified, added, and refined their art.

During the final weeks of the study, children reflected on how humans impacted the kelp forest, and wanted to communicate the importance of addressing and preventing further damage to our oceans. As a result, the children created pamphlets that detailed not only information on kelp forests, but also on how humans impacted and disrupted the ecosystem. The pamphlets were then distributed around the larger school community, urging others to take action in helping and reversing the negative impact humans had made on the kelp forest (e.g., overhunting keystone species such as sea otters, microplastics impacting microscopic plankton).

2.2. Data Source

As the goal of this paper is to examine how children's art illustrates sensemaking of dynamic spatial thinking in STEAM education, I present a focal group collage as a representative example of findings from the collage-making activities. The focal group presented in this paper included five children: Ray, Ara, Kendra, Beverly, and Hudson (Figure 2). By presenting my analysis of the focal group, I provide an in-depth examination of the group artwork that was created over the three collage-making days. I track the changing and evolving ways in which children utilize spatial reasoning to develop and illustrate the dynamic and complex interdependent relationships in the kelp forest ecosystem, and how humans disrupt or impact the ocean.



Figure 2. Ray, Ara, Kendra, Beverly, and Hudson collage-making.

The first collage-making activity was forty-five minutes long and took place three weeks into the study. The second collage-making activity also took up forty-five minutes of class time and occurred two weeks after the first collage-making activity. The final collage-making activity took place three weeks after the second collage-making activity. As this was the final collage-making day, children requested more time to complete their collages. For this reason, we allotted a total of ninety minutes of class time for the last day of collage-making.

2.3. Sensemaking Spatial Thinking in Kelp Forests: An Analysis of Children's Art

Building on modern perspectives of spatial reasoning, I analyze children's collages as an act, or process of sensemaking by presenting my analysis of the focal group's collage over time [32]. I consider how spatial reasoning skills in children's art can be part of STEAM education by reviewing how the collages reflect the dynamic interactions of the kelp forest. In line with scholars who argue for spatial reasoning as a dynamic form of sensemaking, my analysis of children's collages identifies how three aspects of spatial reasoning (scale, orientation, and perspective-taking) have been utilized and developed over time as children make sense of the complex and interconnected ecosystem.

Spatial scaling is how we work with different sizes of the same object [2]. We can see this during play when children often interact with toys and dolls that are smaller versions of objects and people in the real world. Maps are another way to illustrate scaling in spatial reasoning [1], because they illustrate the real world on a smaller scale. For instance, larger bodies of water like the Pacific Ocean will take up more room on the map compared to smaller oceans like the Indian Ocean. Larger continents like Africa will also be illustrated larger than continents like Australia.

Spatial orientation is how we position (e.g., front of, behind) and identify the direction (e.g., up, down, right, left) of objects in space [1,39]. It asks us to know where we are and how to get around in our world (e.g., navigating, map reading). For example, I might stand in front of the street facing the road because I am waiting for the bus, I might walk next to the library to go inside a café, or I might reach for the book next to the dictionary on the shelf above the cabinet. In other words, spatial orientation asks us to navigate and make sense of the position and direction of objects as we travel and move through the world [2].

In perspective-taking, we not only consider how different viewpoints may affect the visibility of objects, but imagine and predict how objects move through space. Depending on your location or position, the visibility of an object can differ. For example, a tree that is visible to you may be partially hidden from your friend standing across the street. In addition to the visibility of objects, perspective-taking can also impact how the sizes of objects appear. A tall building might look shorter if you are standing on top of a hill compared to if you are standing directly underneath it. Perspective-taking also takes into consideration the dynamic vantage points of moving and navigating in our world by imagining and predicting what we might see after a physical movement [1,4].

3. Results

Prior to the first collage-making activity, the children in the study had already researched and created costumes of the sea creatures of the kelp forest. They also played in the classroom with their costumes to embody and explore the interdependent relationships of the ecosystem by pretending to eat one another. The prompt given to children at the start of the art activity was to create and represent the kelp forest.

3.1. First Collage-Making Activity

In the first collage-making activity, the children in the focal group illustrated five species: an orca, sea otters, sea urchins, a fish, and several plankton (Figure 3).

When we examine how scaling is taken up in the first collage, we see that the children took time and care to communicate the size differences between the five species. Not only are the sea creatures drawn to the appropriate proportions, but the children also found a way to illustrate microscopic parts of the kelp forest that are not visible to the naked eye. For example, the size of the orca is larger than those of the fish, sea otters, urchins, and plankton. The urchins that the three sea otters are holding are small and fit into the forefeet. The microscopic plankton is illustrated with "zoom-in windows" so that the details of the plankton can still be shown in a way that reflects the size differences across the five creatures.

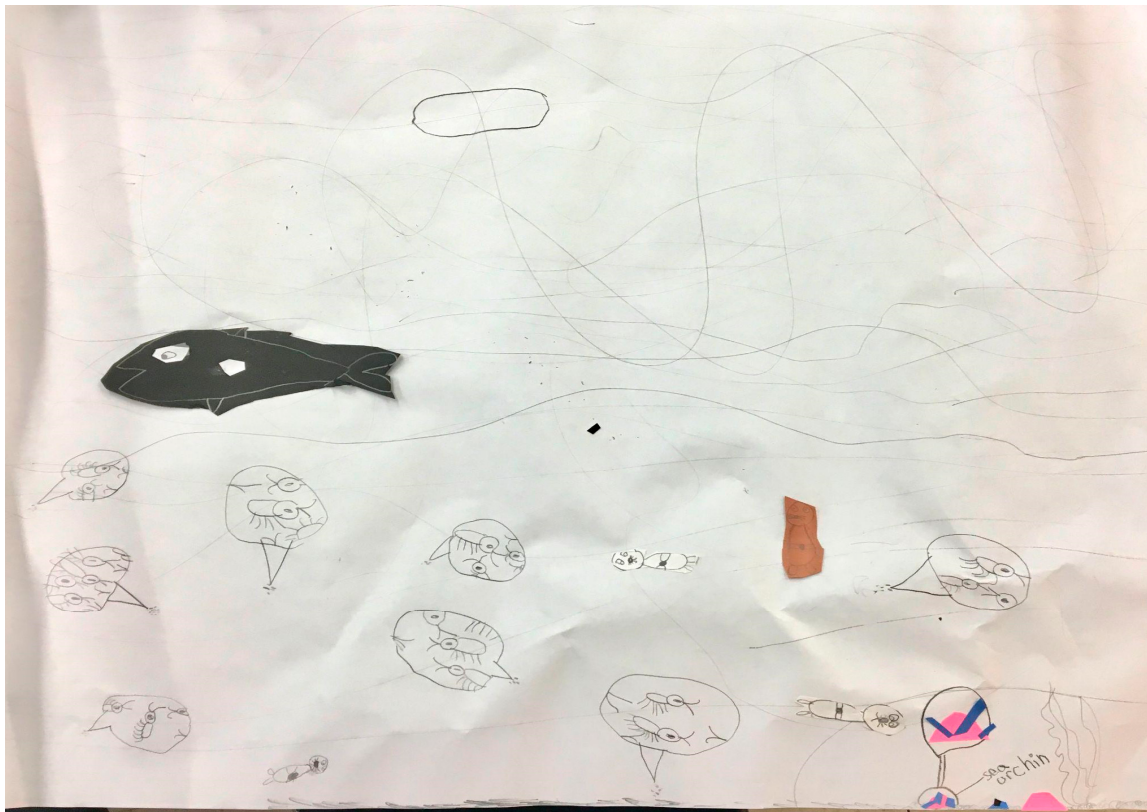


Figure 3. First collage.

While most of the artwork lacks spatial orientation, the sea otters and the urchins are positioned and orientated within the larger food web. On the lower right, we see an otter placed in a manner that indicates that it is moving toward the urchin at the bottom of the ocean. We continue to see this relationship between otters and urchins, as every otter drawn on the page is holding an urchin. However, when we examine the orientation of the remaining pieces of the collage, there is not a clear position or direction for each sea creature. The plankton, for example, is drawn on almost a horizontal line across the page, with no sense of how it relates to the other sea creatures illustrated alongside it. Additionally, when we look at the fish at the bottom left corner and the orca placed on the left side of the collage, it is not clear if they are swimming toward or away from other objects. Overall, while there are emerging spatial orientations visible in the relationship between sea otters and urchins, the remaining pieces of the collage lack an illustration of purposeful relationships and directions.

The perspective-taking of the first collage is closely tied to the overall lack of spatial orientation. With a lack of direction and positionality, the sea creatures are illustrated in ways that seem static and disconnected. The visibility of each sea creature is equally distributed and spread out across the page, which does not provide any information on how these creatures might live and move differently in the ocean. As both the fish and orca's positions and directions are unclear, how they would be moving, and where they are going, are also vague. This analysis also applies to the several clusters of plankton drawn horizontally across the paper. There is not a clear direction or reason for why the plankton is positioned in this way, which makes identifying the plankton's movement within the ecosystem also ambiguous.

3.2. Second Collage-Making Activity

Prior to the second collage-making day, children learned about the different sizes and shapes of kelp and marine creatures through play. In the second collage, we can see several

additions made to the kelp forest ecosystem. The group added kelp (tall algae), a group of sea otters, another whale, and a yellow sun to their artwork (Figure 4).



Figure 4. Second collage.

With the addition of the kelp, we continue to see appropriate scaling utilized throughout the collage. As kelp is a tall and fast-growing alga, it is illustrated as the tallest component of the artwork, beginning at the bottom of the paper and extending toward the top of the ocean where the orca and whale are placed. Interestingly, the orca is moved toward the top of the page—in the first collage-making activity it was originally placed toward the middle of the paper. Here, we see the beginnings of children illustrating the intertwined and interwoven nature of spatial reasoning and STEAM learning. As kelp must be the tallest component on the paper, previous items need to be revised and moved in order to accommodate the appropriate scale of the kelp.

The addition of kelp also significantly impacts the orientation of the artwork. In the first collage, the creatures are statically distributed across the page. Here, we see the knowledge of the food web of the kelp forest ecosystem shaping how creatures are organized and orientated on the page. In addition to the placement of the orca being revised to be at the top of the kelp, we see other creatures like urchins and otters orientating toward their food source. For example, sea urchins crawl on the ocean floor and eat kelp. In the bottom right corner, the newly added kelp is placed next to the sea urchins. The addition of the sun is also important to note, because kelp absorbs and uses sunlight through photosynthesis to grow.

As the dynamic pieces of the food web begin to take root, children's perspective-taking of objects starts to illustrate the movement of creatures in the kelp forest. We can see this most clearly when we examine the new cluster of sea otters in the top right corner of the collage. Many of the otters are drawn at angles, showing the way in which otters dive and move in the kelp forest as they look for sea urchins. Additionally, the variety of angled

positions very clearly illustrates movement in a way that helps us to predict where the otters might go next.

3.3. Final Collage-Making Activity

The final collage-making day took place the day after a play-based lesson on how humans impact the ocean ecosystem. The children had extensive conversations on plastics and microplastics and how the decline of one species within this ecosystem would ultimately have effects on the larger food web. In the final collage, we see an abundance of revisions and additions, as the students had ninety minutes to finalize their artwork (Figure 5).



Figure 5. Third collage.

We continue to see children utilize scaling in ways that reflect the size relations of each component of the kelp forest ecosystem. Orcas continue to be the largest, kelp is the tallest, and urchins are small and spiny at the bottom of the ocean. In the previous two versions of this collage, we saw a steady use of scaling to illustrate the appropriate size and proportions of these kelp forest creatures. However, in the final collage, children also used scaling to show the dynamic food web. For example, there is a newly added group of sharks on the left part of the artwork. The sharks are drawn larger than fish because, as we can see, sharks eat fish. Analyzing the collage as an artifact reveals the appropriate sizes of each component of the kelp forest ecosystem. However, when we consider how this collage is an act or a part of the larger embodied learning experiences of the STEAM curriculum, we see how the differences in size are also bound to how the creatures move in the food web. Sea urchins are smaller than otters not just because this reflects the real world, but because they need to be small enough for otters to grab and take back to the surface to eat. Similarly, orcas are larger than otters because they hunt and eat them.

The final collage illustrates multiple orientations that are, once again, interwoven into children's understanding of phenomena. As in the previous collage, we see the kelp

playing a large part in how the individual pieces of the artwork are orientated. We also start to see variety in the orientation of creatures, as orcas are positioned on top of the kelp, above the kelp, and even diving down into the kelp. This is significantly different from how creatures were positioned in the first collage. Many of the items were distributed across the page, giving no clear indication of direction and position in relation to other creatures. However, we now see that many creatures have different orientations, and how they are orientated depends on how they live and move in the kelp forest. As kelp provides shelter and coverage for smaller animals from predators, we see fish and otters swimming up and in-between the kelp. There is also an abundance of sea urchins gathered at the roots of the kelp on the ocean floor. Therefore, the most significant finding in how children utilized orientation in the final collage is that the decision to position creatures was connected to how they navigate within the space of the kelp forest, showcasing an understanding of the food web and predator–prey relationships.

Additionally, as the children varied their orientation of objects across the artwork, we also see perspective-taking emerge across the page. Compared to the first collage, where the visibility of each object was equally distributed across the page, we see a more dynamic and layered view of the kelp forest. Whereas the first collage had no depth or perspective, sea creatures now dive into, swim up, swim behind, and swim over other objects. For example, as the orcas dive up and down to hunt for food, their bodies swim over kelp, causing parts of the kelp to be hidden from our view. Similarly, otters are swimming on top of the kelp as they return to the surface after finding urchins.

In addition to the varied visibility of objects, we also see a dynamic way of perspective-taking. One of the biggest additions to the collage is the use of arrows as a method of showing how objects move and relate to one another. The kelp has arrows pointing to the sun because it grows through photosynthesis, arrows connect urchins to kelp, otters have arrows connecting them to urchins, orcas are connected to otters, fish are connected to sharks, and zooplankton eats phytoplankton. Once again, the combination of orientation and the use of arrows makes the movement of creatures visible. It also creates a clear picture or story that makes predicting what happens next to these creatures imaginable. Therefore, not only did children utilize perspective-taking to show the different visibilities of objects as they move in space, but they also considered the dynamic and interdependent nature of the kelp forest creatures to one another.

As aforementioned, the final collage-making day took place after a play lesson on how humans impact the ecosystem. Children had already developed an understanding of the importance of balancing the populations of kelp forest creatures (e.g., otters being a keystone species helps to keep the urchin population balanced, so that kelp forests are not overeaten). While considering how delicate, complex, and intertwined the food web was, children also began to gain insight into how easily humans can devastatingly impact ocean ecosystems. When the children finalized their collage, they added trash and pollution across the page, illustrating for the first time how humans fit into this space. On the lower right (Figure 5), you can find an empty blue milk container (another milk container can be found above a fish at the center of the artwork). You can also find a large pink container labeled “Pink Lemonade” in front of an orca in the center of the page. What is most important about this analysis is how, over time, children’s understanding of the kelp forest evolved, and how spatial reasoning helped communicate the complexity and stance of the phenomena they were investigating. It also allowed several domains, including mathematics and science, to be visible and cohesively communicated across the artwork. Finally, we also saw how children’s understanding of the kelp forest was critical and meaningful enough that the awareness of how humans impact our oceans became part of utilizing and making space for telling this story.

4. Discussion

Across the three days of collage-making, the children’s art mirrored and reflected their ongoing sensemaking of the kelp forest ecosystem. We see evidence of this, as the

children's use of the three aspects of spatial reasoning notably shifted across the three collages. The significance of this finding is how the complex and sophisticated use of scale, orientation, and perspective-taking developed as an inseparable part of illustrating the kelp forest. For instance, in the first collage, children primarily utilized scale to illustrate some of the species that live in the kelp forest. However, the components of the collage were distributed and scattered without a clear sense of orientation or perspective. In other words, while some of the pieces of the kelp forest were represented across the page, there was no clarity on how they related to one another.

After the children had learned about the food web, the second collage began to utilize more spatial reasoning skills to illustrate how components of the kelp forest connected and moved in relation to one another. The most notable change in the second artwork was the addition of the tall kelp. The addition of kelp orientated the objects in ways that provided more clarity on how the pieces of the collage interacted in the ecosystem. For instance, the orca, which was originally placed at the center of the collage, was moved up in order to accommodate the taller object. Along with the shifts in spatial orientation, the collage also displayed the beginnings of perspective-taking. Again, these emerging illustrations of perspective-taking were rooted in science, or an understanding of the food web (e.g., otters dive to find sea urchins).

In the final collage, we see a more complex and dynamic piece of art, as the children began to utilize aspects of spatial reasoning in multiple ways. What makes spatial reasoning visible and relevant in everyday life is the dynamic ways in which we interact and move in our geometric world. Ecosystems are not static organizations of objects in space; they are vibrant systems made up of interwoven and interdependent relationships. Over the three collage-making days, we see children moving from a static to a moving and living representation of the ecosystem. We can see this trajectory most clearly when we consider the ways in which the children included the use of arrows to concretely illustrate the predator–prey relationships between all of the creatures.

The final collage also showcased how humans interact with, or interrupt, this ecosystem. Through the addition of plastic trash into the collage, we see that children understood not only the relationships and interactions within the kelp forest, but also the relationships and interactions between humans and the ocean. Therefore, not only was spatial reasoning a resource for organizing how to document and represent the kelp forest, but it became a part of the journey of learning critically how humans impact ecosystems over time. In other words, spatial reasoning comprised more than mathematical ways of representing knowledge; it also became an essential part of understanding the dynamic systems that make up our world. As a result, the way in which spatial reasoning was taken up and utilized in children's art grew more complex and detailed as they learned about the interdependent relationships in the kelp forest over time.

4.1. Implications of Spatial Reasoning in Children's Art

The analysis of children's collages over time demonstrated the importance of viewing art as part of the sensemaking process. Art is more than an artifact that reveals what children know and think about the world we live in. It is also an act, or an inseparable part of the sensemaking process in understanding our world [32]. We saw this through the powerful ways in which children shifted their use of spatial reasoning skills (scale, orientation, and perspective-taking) over time. Therefore, it is important to recognize the essential role of art in developing spatial thinking, not just as a standalone activity, but as an embedded part of classroom practice, so that children are continuously given opportunities to learn from art.

Findings also revealed that through art, children can understand and clearly articulate the complex relationships that make up dynamic systems. This has direct implications on how art can expand how we teach and learn spatial reasoning, moving beyond isolated tasks on manipulating and transforming shapes [29]. It also clearly illustrates the critical and dynamic aspects of spatial reasoning, furthering the argument that spatial thinking is

interwoven in multiple domains. As spatial thinking is a dynamic method of understanding the relationships of our world, future work can consider other forms of art (storytelling, drama, etc.) as a part of learning spatial reasoning in classrooms. Additionally, future research should consider the full potential of art as a part of learning and sensemaking across a wide range of disciplines over different timescales.

4.2. Implications for Designing Sustainable Curriculum

The purpose of this study was to center spatial reasoning as a part of dynamic sense-making in STEAM education. The analysis of a children's collage over time revealed the inseparability of spatial thinking from understanding phenomena and complex systems. This was clearly seen over time as children orientated and organized their art in different ways to reflect their understanding of the kelp forest. We also saw the beginnings of how children understood the ways in which humans impact the ocean ecosystem. As a result, this paper speaks to sustainability in education by illustrating the potential of spatial reasoning in STEAM learning as part of environmental education.

We live in an ever-changing world, with hotter temperatures, droughts, fires, the extinction of species, and warming and rising oceans. The need to understand the way in which humans impact, interact, and relate to the natural world has never been more important in building and creating a sustainable future. In response to these ongoing climate issues, there has been a call for environmental education and climate literacy [19]. If spatial reasoning is essential to understanding the relationships and interactions of the natural and human world, then it should also include recognizing and addressing climate and environmental issues. In the final collage-making activity, children not only illustrated the dynamic relationships of the kelp forest creatures, but also considered the interactions between humans and ocean ecosystems. The addition of trash into the kelp forest not only showed the stance children had on plastic pollution, but showed the potential of utilizing spatial reasoning to understand the relationships between humans and the natural world.

The findings from this study have implications for developing and understanding how we can design environmental education and teach climate literacy. Through spatial reasoning, we can support children in cultivating an awareness of how objects in our world relate to, and, ultimately, impact one another, including the consequences of humans interacting with natural ecosystems. However, if we want to sustainably implement spatial reasoning and teach climate literacy for all, we must honor children's educational dignity as capable and respected learners. Espinoza and colleagues define educational dignity as, "the multifaceted sense of a person's value generated via meaningful participation in substantive intra- and inter-personal learning experiences that recognize and cultivate one's mind, humanity, and potential" [40] (p. 19). Affirming children's dignity as learners requires us to respect and honor children's multimodal resources, including art, play, embodiment, and affect or emotions. Therefore, creating a classroom culture of educational dignity requires us to embrace learning experiences, like play and art, that have historically been positioned as the opposition of learning [41]. If the field wants to create education for sustainable futures that cultivate children's minds and identities as climate-literate individuals, then we must respect children's ideas and voices, and value activities like art and play.

4.3. Conclusions

As we consider how we can create sustainable environmental education for schools, spatial reasoning can be a powerful tool for understanding the relationships and interactions between humans and the environment. This furthers the aforementioned literature that argues for spatial reasoning as part of multiple domains, moving spatial thinking past mathematics and toward a critical understanding of how the shapes and objects in our world are organized. The findings from this paper demonstrated this potential, as children utilized spatial thinking to illustrate the complex organization of the kelp forest ecosystem. They also began to identify how humans interact or impact ocean ecosystems

by adding plastic trash and pollution into the final collage. Therefore, spatial reasoning is an essential part of understanding environmental issues, as we critically reflect on how humans interrupt and impact the organization of the natural world. Most importantly, as we consider spatial reasoning as a dynamic method for critically understanding our world, we must affirm children's educational dignity and value children's participation in multimodal ways of learning [40]. By providing children with opportunities to participate in sensemaking experiences such as art, embodiment, and play, we can support children in being literate in environmental issues, while cultivating activist identities that strive to create a sustainable future.

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