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The Potential of Purposeful Play: Using the Lens and Language of Crosscutting Concepts to Enhance the Science and Engineering Practices of Play

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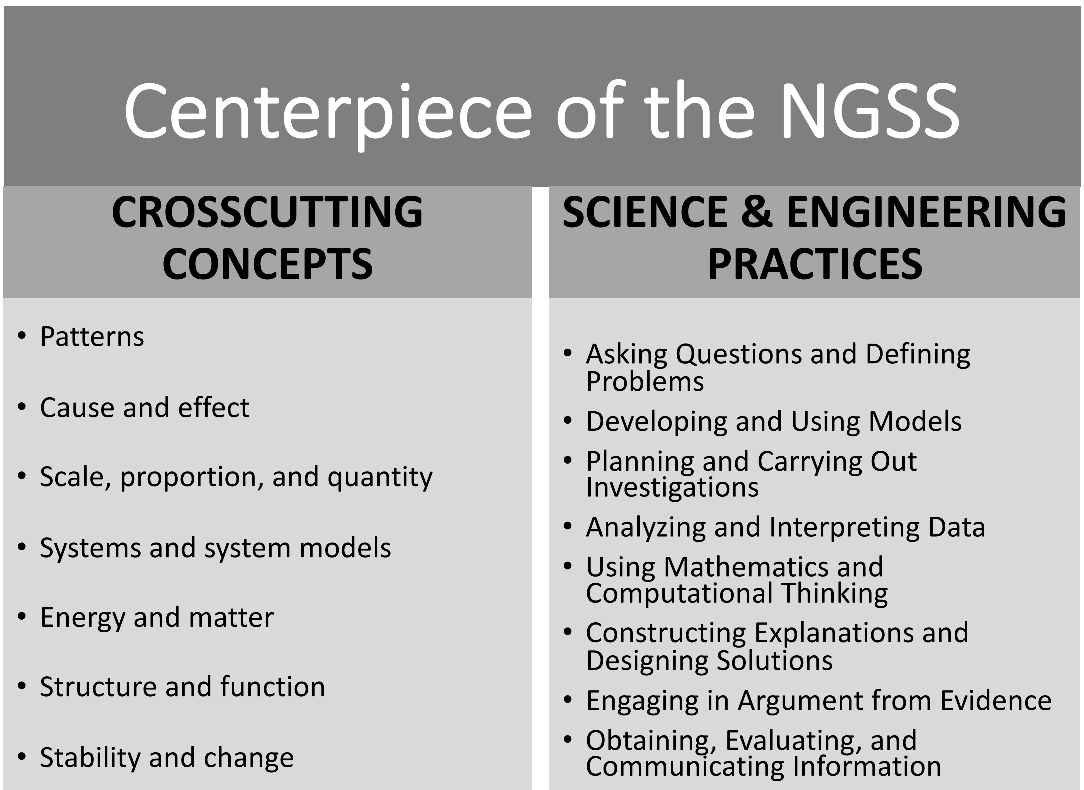
Playing enhances learning. Teachers who recognize and foster the science and engineering practices of playful endeavors push the envelope of children's thinking. Play is purposeful learning, and it serves an important role in human development. Researchers define play as exploratory, process oriented, intrinsically motivating, and freely chosen (Lozon, 2016). The notion of tinkering, often associated with play, has underpinned forward-thinking children's museums and science centers for decades. This creative expression enhances deep learning when supported by intentional guidance (Bevan, Petrich, & Wilkinson, 2015). For the purposes of the current discussion, the authors found that the crosscutting concepts of the Next Generation Science Standards (NGSS, 2013) provide a powerful lens and language through which to provide the type of guidance that challenges students' thinking and enhances the natural science and engineering practices of children's play.

Playing with Purpose

Play is most often attributed to early childhood, and science and engineering most often associated with secondary education and beyond. Yet, play, science, and engineering are interconnected, essential ingredients of quality educational programs throughout the age span. Here, the authors highlight how teachers can introduce into their pre-school and elementary school classrooms vetted “playful” curriculum that, with teacher scaffolding using crosscutting concepts, fosters the development of students’ science and engineering practices. When educators recognize the role of play, appreciate scientific reasoning, and make room for engineering, we honor the learners’ experiences as they naturally unfold across all subject areas. The Science and Engineering practices and the crosscutting concepts of the NGSS (2013) (see Figure 1), along with the voluminous research on play, inform this article.

Figure 1: Science and Engineering Practices and Crosscutting Concepts



Teachers who look at children’s self-initiated play as engagement in science and engineering practices serve as mentor co-researchers with the children. Teachers who intentionally create playful challenges in their classrooms serve the same role. Play experiences, either child-initiated or teacher-prompted, are times when teachers can use language specific to the crosscutting concepts to narrate what they are observing and pose questions. The following sections describe two examples.

From Problems to Practices

A preschool teacher observed a 4-year old building a creature from plastic blocks using different shades of green from an assorted box of connecting plastic pieces. After the teacher's statement, "I see you built something with different green blocks, tell me about it," the child pointed out the creature's two arms, two legs, torso, and head. "It's a monster." The teacher suggested the child draw the monster so her parents could see what she built, but they had a problem -- there was no green paint.

In a STEM lesson on color matching in a 5th grade class, students have the same problem – no green paint. The teacher in this class also encourages science and engineering practices, and uses cross cutting concepts as the lens and language through which to scaffold children's playful pursuit of the "perfect green." Students begin with a quest to make a solution to match the color of the character of their choice. Pictures of popular, green, animated characters are on the table, and the children try to replicate the different greens. With the red, blue and yellow water available, the children get started on making their paint batches.

Making Green? In preschools and elementary schools everywhere, young children make secondary and tertiary color pigments from primary colors. What is different here? The difference is that the teachers are intentionally and mindfully focusing children's attention on *asking questions* about the shade of green, *defining the problems* of what colors to combine, using the colored water as a *model* of the face or fabric of their chosen character, *carrying out their plan and documenting* how many drops of each color they use, *analyzing* their colors as they compare to the green of the character, using the commutative and associative principles of mathematics in the natural context of drop counting (without using the terms commutative and associative), *building their computational thinking* (totaling their drops), and *showing their evidence* (their batch of green) to classmates to determine if others find their green a "perfect match." The children's efforts mirror science and engineering practices. Students investigate concepts of *scale and quantity* as they add primary color volumes to create their batch of color to match the characters. This is a cross-cutting concept.

These two classrooms are on a similar mission – maintaining the joyfulness and high- energy tone of real learning in structured learning settings with goals, standards, accountability, and evaluation. The authors found that the practices and concepts of NGSS point the way. Play can be deliberate, intentional, replicable, quantifiable science and engineering practice, and NGSS helps us understand the power of play in STEM learning.

Playful Curricular Challenges

Lessons are developed around the core ideas of NGSS, with a particular focus on the practices and concepts of the NGSS by crafting playful curriculum problems that are challenge-based, with design thinking and career awareness at the core. Fifth grade students were engaged in a color matching challenge through science and engineering practices, as they specifically relate to core ideas in chemistry, art and math disciplines.

The following represents the playful challenge: *"You are a color technologist, and your role is to design a formula for the green that matches different animated characters. When the color satisfies the artist in you, hand off your formula, and ask a classmate to make a batch. Does your friend agree that the formula matches the color?"* The careers of technologist and artist are used in this lesson to informally plant seeds that multiple future opportunities exist, and these opportunities tap into STEM interests, passions, and skills in careers that may not routinely be seen. Other careers are used in other lessons, each with varying educational levels required. The task to make a specific color requires the student to engage in design thinking. The approach and procedure for making the batch generates from within the child. Having a friend replicate the formula mimics the scientific enterprise by validating or refuting student's work. Tracking the formula embeds math into science practices as an essential feature of the investigation. STEM practices, in general, are embedded by the design of the challenge.

Responsive Teacher Language

Once the playful curricular challenge is in place, teachers' responsiveness to students enriches children's engagement, interest, actions, reasoning, creativity, and commitment within the challenge. Teacher language using clear targeted questions and statements filtered through the lens of the crosscutting concepts can extend students' current engagement in the curriculum play into intentional science and engineering practices at the leading edge of the students' thinking. The following illustrates teacher language rooted in the crosscutting concepts through examples within the color matching challenge.

- Structure and Function
    - "You thought that adding yellow would make your green brighter. But, you say it didn't. Sounds like the yellow did not function as a brightener. What is your thinking now?"
- Stability and Change
    - "It sounds like you're saying that each drop of a new color changes the old color. Is that right?"
- Energy and Matter
    - "The sample seems to look different to me in different light. Does it to you?"
- Pattern
    - "I see that when you added a drop of yellow to blue, you made green. What do you imagine would happen if you were to add more yellow?"
- Cause and Effect
    - "I see you were surprised when you added the red. What effect did the red have on your green?"
- Scale, Proportion, and Quantity;
    - "I see you are using counting to fill the pipette. Sounds like you are using time as a measure of "how much." I haven't before seen this method. How did you come up with it?"
- Systems and System Models
    - "You said you added too much blue, then I see that you added more yellow to your batch. Getting the right green seems to be a whole system of drops of blue, yellow and red. How are you monitoring your process?"

A Revisit

The authors found that learning to use the crosscutting concepts with ease in a classroom is a journey that requires multiple examples and experiences. Few have participated in learning settings rooted in these big ideas and few have had long term exposure to learning settings that invited engagement in science and engineering practices.

Consider two other examples, both still on the topic of pigment color. In an outdoor class of 4 - 5-year-olds, students were working with multiple planters filled with basil, spinach, tomatoes, and other herbs and vegetables that they planted earlier in the school year. Looking at one of the tomato plants, the children noticed a creature on one of the leaves. The children had not noticed the creature before, but, as one child stated, "The worm is camouflaged." The teacher asked, "What makes you say that?" The child confidently stated, "the worm is green on green so it's camouflage." The teacher speculated with the children how they would draw the creature if it was already green on green. The children wondered how they were going to make two colors of green so they could see the creature in their own drawings.

The children in this class are *self-defining problems* (they want to create a color for the plant they are observing, but also want to create a different color green to represent the caterpillar they found camouflaged on their tomato plant), as they continue *carrying out investigations* (how do they make different greens and how do they draw what they want to draw). Teachers can direct student engagement in further science and engineering practices at potentially more sophisticated levels (looking at the difference between leaves and leaves with creatures on them) by drawing students' attention to *measurement or quantity*, a crosscutting concept, with questions such as, "Could there be a little tiny bit of another color in the green of the bug?" This sort of question sets the stage for young students' thinking about *measurement, or quantity* (How many drops of yellow and how many drops of blue and how many drops of another color will make that shade of green?)

In a 4th grade lesson, children are also exploring pigment colors, but adding a new medium, milk, with the colors. Like their younger counterparts with the caterpillars, they are also *defining problems* (in this case, the colors do not mix) and *carrying out investigations* (Why don't the colors mix). Teachers can direct student engagement in further science and engineering practices at potentially more sophisticated levels (looking at distinctions in different types of milk) by drawing students' attention to quantity with a statement such as: "Does the % fat in the milk make a difference in the color mixing," and, "What about almond milk?"

Literacy and Numeracy Development within Design Thinking

Coming back to the example of the green creature on the tomato plant, it looked like a caterpillar, and the children wondered about the kind of bug, how it got on their plant, and what else they could let it eat so it would not eat the tomato plant in their garden. The children were playing. The children were engaged in science. The children were designing their process. The teacher helped them find books about garden creatures to help identify it (research, literacy, language). The children concluded it was a caterpillar, observed it for days, and took notes wondering what would happen next (scientific thinking, literacy, language). They drew pictures on the calendar to show change across time and measured the creature periodically (mathematics, data collecting, and science). Student-led questions turned into investigations, and the investigations naturally included science, art, language, writing, and mathematics.

These types of curriculum problems, either student-generated or teacher-generated, extend and reinforce important concepts across subject domains within a safe and nurturing, yet provocative and demanding learning environment. The approaches described here are based on the pedagogy of constructivism (Brooks & Brooks, 1999; Brooks, 2011) and the principles of universal design for learning (Pisha & Coyne, 2001). Both constructs anticipate a wide range and complexity of learner needs, thus, the learning spaces and tasks are flexible by design and accessible for diverse classes. This type of teaching requires a teacher to think *along with* the children.

In Conclusion

Play and learning go hand-in-hand. Play helps us to test and symbolize our knowledge of the world, communicate an understanding, and build toward later academic learning (Saracho, 2012). Teachers who provide intentional opportunities for play enhance children's learning of core ideas, as well as the development of feelings of worthiness and the skills of academic competence. Playful learning with a skillful teacher inherently engages students in meaningful scientific thinking.

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