Double Impact: Mathematics and Executive Function

Modify activities according to these principles and suggestions.

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The teacher displayed counting cards that included both dots and numerals in order from one to five, as she counted them with her students. She then turned the cards facedown, keeping them in order, and began an identify-a-hidden-card activity with the class.

JOEY333 (STUDENT); KLERIK78 (SPIRALS); PIXEL_DREAMS (NUMBERS)/GETTY IMAGES

Teacher: Pete, can you point to a card, please?

Petrov: [*Points to the second card from the left*]

Teacher: Thank you. I know that is card "two"! Pete, can you turn it over to show the class?

Class: [*As Pete shows the card*] Two! It's two!

William: How'd you do that?

Petrov: She counted in her head. One [*pointing to the first card*], two [*holding the "two" card as high as he can*].

Teacher: Amelia, what card is Pete holding up?

Amelia: Two.

Teacher: How do you know it is two?

Amelia: I see two dots [on the card].

Teacher: How else can you tell that this is card two? Naomi?

Naomi: There's a two on the card.

This class was engaged in the third of three card activities that develop number sense and number skills. In this article, we describe how we have used and modified this activity both to develop mathematical competencies and to develop important higher-order, or executive function, skills. We conclude by providing strategies for modifying any mathematics activity to similarly get "double impact"—simultaneous development of young children's mathematical proficiencies and executive function skills.

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Prekindergarten students enjoyed the card activity and pretended they had X-ray vision.

Two activities to develop executive function skills

To begin, consider the first two activities: ordering cards and identifying the missing card. The Order Cards activity asks children to arrange a set of numeral cards in a row, 1–5 or 1–10 (all activities are from Clements and Sarama 2013). The What's the Missing Card? activity extends the Order Cards activity by asking children to identify a card that has been removed from the row. Such activities engender the number concepts of ordinal counting, numeral recognition, number order, and the successor, or number-after, principle that are essential learning in early childhood mathematics but often are not developed in depth (Clements and Sarama 2014; Sarama and Clements 2009).

So far, so good. However, despite their moderate to high mathematical demands, neither activity does much to help children develop other executive function (EF) skills. What are these EF skills? How we can develop both high mathematics and executive function competencies by modifying activities?

EF processes allow people to control, supervise, or regulate their own thinking and behavior and are critical for young children's learning (Clements, Sarama, and Germeroth 2016). For example, EF predicts math achievement as well as success in school broadly (Clements, Sarama, and Germeroth 2016). Most teachers rate such EF components as inhibition and attention shifting as important for math thinking and learning, and these ratings increase with teaching experience (Gilmore 2014). Some researchers argue that EF processes constitute "a major characteristic of productive mathematics learning" (De Corte et al. 2011, p. 155). Interestingly, many studies show that EF is associated more highly with mathematics than literacy or language (e.g., Blair et al. 2015; see a review in Clements, Sarama, and Germeroth 2016; McClelland et al. 2014).

EF includes three categories: (1) inhibitory control, (2) working memory, and (3) attention shifting and cognitive flexibility. *Inhibitory control* allows one to keep from acting impulsively. Consider the following problem:

> There were six birds in a tree. Three birds already flew away. How many birds were there before some flew away?

Children must inhibit the immediate desire to subtract engendered by the phrase *flew away* and instead calculate the sum. *Working memory* allows one to both hold information in short-term memory and process that information. Children solving a measurement problem may have to keep the problem situation and their solution in mind while they perform a necessary computation, interpret the result of the computation in terms of the measurement units, and then apply that to the problem context to solve the problem. The third category, *attention shifting and cognitive flexibility*, includes two closely related EF processes that are considered simultaneously. They allow one to switch attention as a situation requires and be flexible in thinking. For example, children may have to count meters and then centimeters as part of a meter or abandon a "rule" they determined in a Guess My Rule game when a new example is inconsistent with their original thinking.

Despite the importance of EF, efforts to help children develop it—and those with fewer home and community resources especially need that help—have, at best, mixed results. Computer games and other direct training approaches of EF have been moderately successful in only some studies, and the effects seem limited to those specific contexts (Clements, Sarama, and Germeroth 2016). Fortunately, a bidirectional relationship between math and EF appears to exist—the development of one seemingly promotes the development of the other (Clements, Sarama, and Germeroth 2016). So, because developing both EF processes and mathematical proficiencies is essential for young children, high-quality mathematics education may have the dual benefit of not only teaching this important content area but also developing young children's EF processes, using precious instructional time wisely.

The X-ray Vision activity

That brings us back to the third activity with cards, identify a *hidden* card, which was designed to include higher EF demands. In the X-ray Vision activity (Clements and Sarama 2013), cards are arranged in numerical order and then turned facedown on the table. One child points to one of the cards, and a partner must use his or her "X-ray vision" to name the card before turning it over to confirm. Then the card is turned back to facedown, and the children switch roles. Of course, children actually

Four-year-old prekindergartner Violet first ordered a shuffled stack of numeral cards and then counted them to ensure they were arranged correctly.

Violet and her teacher turned the ten cards facedown.

must use mathematical processes to determine the identity of the hidden card. (But they still think they are super heroes when they can do it!) The mathematical demands of this activity can be differentiated: Children may count from one, touching each card, until they arrive at the selected card, or count down from the highest card to the selected card.

A second version

In a second version of the X-ray Vision activity, children leave already-identified cards faceup. This encourages students to count on or count down from those cards to the chosen card or to identify a number between two faceup cards (e.g., 4 and 6). This type of Identify-a-Hidden-Card number activity has a high mathematical demand for young children: They must count, using one-to-one correspondence, forward or backward, from one number to another.

Further, the X-ray Vision activity also has high EF demands. The activity engenders each of the three primary categories of EF processes: (1) inhibitory control, (2) working memory, and (3) attention shifting and cognitive flexibility. Violet, a four-year-old prekindergartner, could count ten objects and even produce, or count out, a set of ten items as well as recognize numerals 1–10. She was asked to first order a shuffled stack of numeral cards on the table. Then she and her teacher counted the cards, as they pointed to each, to ensure the cards were arranged correctly before turning them facedown.

The teacher asked Violet to point to any single card, then the teacher said, "Hmm. I'm using my special X-ray vision trick to figure out what number is on that card. Hmmm. I-t—i-s—f-i-v-e!" The teacher then had Violet turn the card over to reveal that is was indeed a number 5. The child, as one might anticipate, was delighted with her teacher's X-ray vision trick!

The teacher had Violet replace card 5, facedown, in the row of cards on the table. "Now, Violet," the teacher asked, "If I chose a card, can you name the number on the card without looking?" After Violet excitedly agreed, her teacher reminded her where the number-1 card was and then pointed to the fourth card in line. "Alright, Violet, what is this card?" the teacher asked.

The child paused and then exclaimed "Four!" as she held up four fingers.

"How do you know it is four?" the teacher asked Violet, incredulously.

She answered, "I counted one, two, three, four," as she looked at, but did not point to, the cards on the table. The teacher then flipped over the selected card and confirmed that Violet had used her own X-ray vision to determine the correct answer.

The X-ray Vision activity allows for the incorporation of inhibitory control, working memory, and attention shifting and cognitive flexibility. For instance, in the introduction to this activity, Violet used inhibitory control

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The teacher and child played a turn of X-ray Vision, the teacher in the role of *selector* and the child in the role of *identifier*.

Before the next round of the game, the teacher reminded Violet where the number-1 card was and then pointed to the fourth card in line.

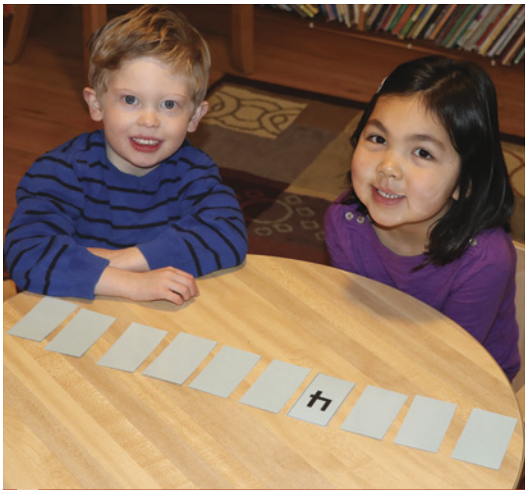
to keep herself from just making a wild guess or reaching to the selected card and just flipping it over to reveal its identity. She used working memory to sort the cards into numerical order to begin the activity and to keep both the location of the selected card in mind and to remember and apply a process to solve the task. Her working memory and attention shifting processes were further used as she and the teacher exchanged selector and identifier roles with one another, taking turns selecting cards for one another and testing one another's special X-ray vision tricks in subsequent games.

In another game of X-ray Vision, played between children, Cooper selected card 8 for Violet. In the previous turn, card 4 had been identified by Cooper and was left faceup. To identify the card Cooper had just selected for her, Violet first touched card 5, saying "five," then "six, seven," as she counted each one. She stopped at "eight," with her finger on the card. This interaction demonstrates Violet's ability to both count on and employ attention shifting.

When Cooper and Violet played as a pair with the teacher, and card 9 was selected, Violet told Cooper that she knew that "ten was the last, and nine comes before." In this think-pair-share version of X-ray Vision, Violet and Cooper agreed on the identity of the hidden card, although Violet articulated her mathematical reasoning in a more sophisticated way than when not given the opportunity to share her reasoning with a peer.

Differentiation

Both the mathematical demands and executive function demands of activities like X-ray Vision can be increased or decreased to accommodate the needs of all learners. For example, to increase the mathematics demand, instead of having a child count from the first card each time, ask students to count down from the highest card or count on or count down from a previously uncovered card. The mathematical demands can be lowered by decreasing the number of cards, such as using only cards 1–5, or by using counting cards with dot arrangements and numerals for children who lack numerical recognition, as was done by the teacher in the opening vignette. Conversely, adding more cards with higher numbers increases mathematical demand.



Violet used her own X-ray vision to correctly determine the number on the card her teacher had chosen.

Many of the modifications used to increase or decrease mathematical demand similarly alter the executive function demands. For example, to increase mathematical demand, the cards need not be arranged in one single horizontal line but can be arranged in an array—cards 1–10 arranged in two rows of five cards, for instance. Such a change increases the demand on a child's use of attention-shifting processes. That is, a child may come to the end of the first row, having counted 1–5, and need to shift attention from counting to making sense of where the next card is placed—as card 6 is now below card 1 and not to the right of card 5. With arrays, some children may be able to subitize the quantity of cards in the first row—say "five"—and begin counting from card 6 in the second row. Counting on from a previously identified card not only increases mathematical demand but also increases the use of inhibitory control processes. Engaging with the same general activity, but with varying structures and emphases or mathematical demand, also increases children's cognitive flexibility. Yet, EF can be increased or decreased without changing the mathematical demand. For example, when choosing a card to identify, children must use working memory to recall which card was selected as they go through the activity process. To decrease the working memory demand, a chip can be used to continuously mark the selected card.

Other ways to decrease the EF demands of X-ray Vision are to decrease various roles that children can play. For example, decrease the EF demands by allowing the child to play only the role of identifier. That is, the teacher will always select the cards, and the child will always name the cards—roles will remain constant. Or increase the EF demands by having children play X-ray Vision in pairs. Using think-pair-share methods, students can confer with each other and then collectively answer which card has been selected. Or have children switch roles: Allow one child to play the selector and one to play the identifier, switching roles at each turn. The demands of each of the EF processes—attention shifting and cognitive flexibility, inhibitory control, and working memory—can be increased or decreased in X-ray Vision. The visual representation shows selected variations of the X-ray Vision activity, suggesting ways to increase or decrease both mathematical and executive function demands.

TABLE 1

A table shows general principles and suggestions for modifying mathematical and executive function demands in activities for young children.

Task modifications

	Mathematics	Attention shifting and cognitive flexibility	Inhibitory control	Working memory
	Provide opportunities and support for children to—			
Principles	*engage in challenging but achievable mathematics activities.*	*switch attention as a situation requires; search for a new strategy if the first one attempted fails.*	*keep from acting impulsively.*	*hold information short term and process or apply such information.*
Suggestions	• Increase or decrease the numbers used. • Change representations (e.g., dot cards or numeral cards) or manipulatives. • Make the activity more or less abstract. • Present oral or written activities. • In general, move up or down levels of a learning trajectory (Clements and Sarama 2013; Sarama and Clements 2009).	• Increase or decrease the number of roles a child plays or switches between. • Increase or decrease the number of steps in the activity. • Present the same mathematical activity in many different ways (e.g., X-ray Vision cards in linear arrangement vs. an array). • Use different contexts for a topic such as addition, including multistep problems. • Give problems that require flexible thinking, such as finding all pairs of positive whole numbers that sum to six.	• Increase or decrease the number of turns children take during an activity (e.g., increase or decrease their "wait time"). • Have children work in pairs (e.g., think-pair-share) to discuss ideas. • Use problems with "tricky" phrasing, such as, "There were six birds in a tree. Three birds already flew away. How many birds were there from the start?" • Encourage positive behaviors and attitudes (Fuhs, Farran, and Nesbitt 2013).	• Increase or decrease the number of and/or demands of the processes for the activity (e.g., how many things a child needs to remember). • Use visual mediators, such as pictures of each step of the activity, then remove them to increase working memory demands. • Have children explicitly state that they are committing an idea (e.g., a number or a card) to memory. • Increase the use and number of steps in multistep problems.

TABLE 2

Activities should be selected on the basis of where children are mathematically and the development of their executive function skills.

Mathematical and executive function (EF) demand matrix

Executive Function Demands	Mathematical demands: Low	Mathematical demands: High
High	Activities here often sacrifice the mathematics for EF. This is undesirable, but these activities could be used sometimes to develop EF when there is already some mathematics mastery. For example, Simon Says-type activities can be useful to develop EF. Counting can be incorporated, for instance, by calling to children to do actions a particular number of times while counting aloud.	Activities here are preferable. But activities with high EF and high mathematical demands can often be very challenging, so mathematics and EF should be supported until children can be given activities with high demands in both. Sometimes activities here may be given as a challenge when appropriate.
Low	Activities that are low in both mathematical demands and EF demands can be great for fun or transition time. These activities can be easy to enact and are engaging for children, but will not necessarily increase their mathematical or EF skills. Time on these activities should be limited or minimized so as to avoid detracting from time spent on more demanding activities.	Activities here are acceptable and common. That is, many mathematics activities have high mathematical demands but do not have a focus on building children's EF skills. Thus, these activities should be used but can be modified to increase EF demands.

Many high-quality mathematics activities for young children can be modified to have high EF demands. One might think of varying demands in activities, both mathematical and EF, like differentiation: Demands may be increased or decreased for children to meet their individual needs and the activity goals. See **table 1** for suggestions.

Designing for optimal learning and problem solving

Asking young children to face high mathematical demands and high EF demands may be overwhelming and inappropriate. So, what is best? To begin, very low mathematics demands are usually undesirable—the mathematics should not be sacrificed for high EF demands unless the activity goal is EF training only, and activities with both low EF and low mathematical demands should be used cautiously (see **table 2**). If they are necessary for some children, those children should subsequently receive additional experiences that slowly but surely increase the demands so they build both competencies, catching up to their peers.

Activities with moderate to high mathematical demands that do not explicitly or intentionally support or demand the use of EF processes are, of course, useful (see **table 2**). If incorporating moderate to high EF demands into activities with high mathematical demands proves too difficult for students, some folding back to lower EF or mathematical demands is appropriate before returning to higher demands. Ultimately, activities with both high EF and mathematics demands are most desirable, but not all children can nor should start there or always be there. Some lowering of either EF or mathematical demands allows for the other area to be emphasized and for some direct instruction or support on EF or mathematics as necessary.

Studies have shown that children's EF processes can be trained and increased through particular curricula and programs that target both content and EF simultaneously (e.g., Bierman et al. 2008; Clements, Sarama, and Germeroth 2016; Clements et al., forthcoming; Raver et al. 2011; Riggs et al. 2006; Weiland et al. 2013). EF may be developed in learning the mathematics in the context of challenging activities, not in "exercising" the mathematics once learned (Clements, Sarama, and Germeroth 2016). And, because both EF processes and subject-matter proficiencies are required to support optimal learning and problem solving, designing interventions that interweave the two makes sense. Teachers may consider using the principles and suggestions in **tables 1** and **2** to modify their own activities for increased or decreased mathematical and EF demands, generating a positive double impact on their students' development of mathematics and executive function.

Common Core Connections

K.CC.1
K.CC.2

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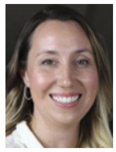



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