Developing Understanding of Dynamic Systems Within Early Childhood Settings

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Abstract:

When beginning to integrate systems concepts and tools within K-12 education more than 20 years ago, the initial mental model of many teachers was that the strategies would be most appropriate for students in middle and high school. Some years later, teachers questioned this initial assumption and began using a variety of strategies with elementary students. More recently, teachers of preschool considered the work for 3-4 year old students, challenging the boundaries even further while also creating developmentally appropriate methods for introducing and developing systems concepts.

Many questions have arisen over time as teachers continue to explore what's possible as they work with the youngest students. Two of these are, "In what ways is stock and flow thinking foundational to developing cognitive capacities and intellectual engagement while working with children ages three through eight, and how do teachers perceive and assess student understanding as they implement a variety of systems thinking strategies?"

To answer these questions, we must first consider why this understanding is important. How does an understanding of accumulations and rates of change, key components in stock and flow thinking, impact a student's ability to see systems more clearly than they would have otherwise? Secondly, how can teachers scaffold student understanding over time, based on age, abilities and background knowledge? Scaffolding, based on a construction metaphor, ''enables a child or novice to solve a problem, carry out a task or achieve a goal which would be beyond his unassisted efforts'' (Wood et. al., 1976). Finally, how does survey data from teachers illustrate impacts on students, both inside and outside the classroom?

The Waters Foundation, Systems Thinking Group has been working with educators throughout the U.S. and world (www.watersfoundation.org) for the past 25 years. Its mission is to "build the capacity of adults to deliver academic and lifetime benefits to students through the effective implementation of systems thinking habits and tools into classroom instruction and school improvement." This paper describes the impact of many years of research and teacher development specific to the early childhood classroom. Through developing the capacity to make trends and accumulations visible, children recognize the nature of dynamic systems and are better able to communicate their understanding to others.

Introduction

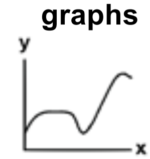
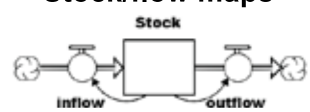
Why is this thinking important?
There has been much research that supports young children's ability to think in complex and abstract ways. Young children are not mired in the fragmentation of learning in specific subjects like math, science or reading. They see the world as naturally connected and interdependent. They do not view problems as challenges that require a specific kind of thinking like mathematical thinking or scientific thinking, but as holistic conditions that call for unbiased observation, unaffected recall, and the wisdom of a beginner's mind ready to discover new insights and understanding. "In mathematics and science, research suggests that children are capable of thinking that is more complex and abstract than was once believed. Curricula that works with children's emergent understandings, providing the concepts, knowledge, and opportunities to extend those understandings, have been used effectively in preschool years..." (Bowman, B, Donovan, S & Burns, M, ed. 2001). When curricula are designed to encourage children to reflect, predict, question, and hypothesize, this results in effective, engaged learning. We have learned that as educators, we often underestimate the innate systems intelligence of young children and that given the appropriate language and tools, they develop surprisingly sophisticated insights about the world around them.

Power of Connections and Dynamic Representations
The ability to make the connection between the model of a system (e.g. diorama of a garden or clay figure of an animal) and the actual system emerges as children mature, but also can be influenced by experience (Galinsky, 2010). "There's nothing that sets human beings apart from any other species on the planet more than our symbolic capacity … a vast proportion of what you know comes through symbolic representation." The visual tools of systems thinking provide children a way to symbolically represent their understanding of everyday systems and encourage them to make connections based on their life experiences. What is unique is that the systems thinking tools show dynamic symbolism, not merely static representation, which is typical in today's classrooms. Even though in early childhood classrooms, graphs, loops and stock/flow maps are usually 2-dimensional drawings on paper, the visuals enable children to show and explain the changes and reasons for change they see in stories and observations of systems. Too often in classrooms, children are asked to build models of dynamic systems using static means (e.g. dioramas, arts and crafts models, drawings) that limit a child's ability to develop and show deeper understanding of systems' variables and interdependences that change over time.

What has also been observed is the level of excitement children have as they use the visual tools to explain their new learning experiences. When parents come to preschool to pick up their children at the end of the day, children insist on using the visuals to tell Mom or Dad about a story they read or about a science observation they had in the outside garden. Even with limited language skills, young children employ the visuals as they retell their experiences with depth and rigor, using language like "increases," "decreases," "quickly," "slowly" and "this happened because…" In addition, there is a growing sense of ownership of the classroom wall charts of graphs and loops. One preschool teacher told us that her children were upset with her when she took down a graph they had made of a story weeks ago. She said, “My students are very protective of their graphs, and don’t like it when I take them down to make room for new work.”

These examples demonstrate the power of behavior-over-time graphs as they facilitate a wide range of essential cognitive skills, impact children’s engagement and ownership of their learning and serve as a foundation for the development of understanding of accumulations and rates of change. Simple stock/flow maps are equally effective in providing children unique and symbolic ways to represent dynamic systems. Often called “bathtub thinking,” children identify a key accumulation and think through the causal factors that affect the faucet and the drain. Behavior-over-time graphs and stock/flow maps provide children opportunities to make their thinking and conceptual understanding visible. The tools, as basic building blocks of system dynamics, help children organize and formulate their understanding of systems and assist in the communication of that understanding.
Specifically, behavior-over-time graphs and stock/flow maps build and reinforce a number of skills (Table 1).

Table 1: Skills and Tools

Skill	**Behavior-over-time graphs** 	**Stock/flow maps** 
Sequencing	X	
Retelling	X	X
Cause and effect	X	X
Pattern and shape transfer	X	
Conceptualization of time	X	X
Inter-textual awareness	X	X
Mathematical reasoning: Seeing things (accumulations) that increase and/or decrease	X	X
Beginning understanding of slope as a rate of change (steepness or flatness)	X	X
Symbolic and dynamic representation	X	X

Asking children to take time to reflect, observe, consider alternatives, make connections and draw on higher levels of awareness are all addressed with this systems thinking pedagogy. The skills in Table 1 have been observed and documented as being supported by both behavior-over-time graphs and stock and flow maps. A brief explanation of each skill follows:

Sequencing is the ability to organize a series of events in proper order. **Retelling** is the ability to accurately recall and tell a story in one's own words or summarize the steps needed to complete a task. Behavior-over-time graphs require children to understand and make note of how time is marked on the x-axis and be able to draw or represent a change that occurs over time. In early childhood classrooms, children make behavior-over-time graphs to show changes in various emotions over the course of a story. Children also use stock and flow maps to **retell** the relationships they see in key accumulations. Their explanations include key variables that cause an accumulation (e.g. level of fear of a storybook character) to increase or to decrease.

The ability to identify **cause and effect** relationships is developed when children explain their stock and flow maps or behavior-over-time graphs. Stock and flow maps provide a way to explain how and why accumulations or stocks change. For example, one might say, "This boy's happiness went up because he got to see his friends." Behavior-over-time graphs help children identify the shape of change as illustrated in trend lines and match those graphical shapes with others, even those that were drawn for other systems at different times. When charts of behavior-over-time graphs that were drawn for different stories hang on the classroom wall, children quite easily identify similar graphs. For example, a variable showing an oscillating trend of an emotion like happiness~~,~~ can easily match that same pattern for a different story that tracked the changing number of friends.

The **conceptualization of time** tends to be abstract for young children. Trouble understanding that one has to wait 15 minutes before snack time can cause frustration because their understanding of the concept of time is still developing. However, when children fully investigate by observing and drawing change over time in terms of graphs and bath tub visualizations (stocks), time becomes much more concrete.

Inter-textual awareness, the ability to recognize stories that have similar patterns, is a foundation for reading comprehension. Children begin to develop inter-textual awareness early on as they are read to by parents and caregivers. In early childhood classrooms, as young children are exposed to multiple stories with similar structure, and use behavior-over-time graphs and stock and flow maps to make those structures visible, they can adeptly identify similarities thus strengthening their inter-textual awareness. Teachers have discovered the power of these tools to develop inter-textual awareness, particularly when children have not had the advantage of rich early literacy experiences.

When children begin to understand increasing (addition) and decreasing (subtraction) as they draw a behavior-over-time graph or map out changes of a key stock in a system, they are developing a **mathematical reasoning** foundation. And, a deeper understanding of how fast or slow an increasing or decreasing change occurs helps develop an initial understanding of **rates of change and slope**.

Behavior-over-time graphs and stock and flow mapping serve as very effective and efficient ways for children to create **symbolic and dynamic representations of systems**. Whether the systems are described in stories, or real life observations, children make their understanding (or lack of understanding) visible when they draw their graphs and maps.

Building a System Dynamics Capacity in Young Children

Scaffolds for Learning and Teaching with a Developmental Frame

Although no exact progression exists, teachers of our youngest learners, from age three through eight, work to scaffold their instruction of systems concepts over time. A child's development, prior life experiences and cultural orientation are important considerations for a developmentally appropriate learning environment (Copple, 2009). By providing appropriate levels of challenge based on individual differences, teachers intentionally plan and apply systems thinking strategies within a developmental framework.

The habits and tools of systems thinking and system dynamics are typically introduced and practiced in cooperative settings. This type of social learning environment with teacher assistance is most effective when the support is matched to the needs of the learner (Wood and Middleton, 1975). Thus, the learning environment is also targeting an appropriate Zone of Proximal Development (ZPD) for every child. The ZPD is defined as, "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers" (Vygotsky, 1978). The ZPD provides children learning challenges with intentional scaffolding to help them achieve success that they would previously not have been able to do alone. Scaffolding is defined as, "Those elements of the task that are initially beyond the learner's capacity, thus permitting him to concentrate upon and complete only those elements that are within his range of competence" (Wood, et al, 1976).

When teaching systems concepts, teachers scaffold in many ways. They reinforce and validate children's efforts to represent their thinking symbolically through drawings, pictures and words (e.g. behavior-over-time graphs and stock/flow maps). They encourage children to explain their dynamic representations and share questions and new insights with one another. What teachers discover is not only the level of understanding of individual children, but the dynamic representations along with the oral explanations help uncover critical misconceptions that can be addressed through re-teaching.

Teachers also use kinesthetic means to scaffold the concepts associated with systems tools. For example, teachers have used chenille sticks (aka pipe cleaners) on a flat surface to show various patterns and trends of change over time. Objects (e.g. Hoberman spheres) that change over time in terms of size or shape are shown changing and children are asked to match the change with their own bodies. As an object changes from small to large, children begin with their bodies curled into a small ball and then gradually grow taller and bigger to match the changing object. Once children experience and describe the change, they can then reflect and represent the change with a behavior-over-time graph. The incorporation of experiential learning, encouragement and guidance are all effective ways to scaffold and provide opportunities for children to extend and challenge their understanding of systems.

Teachers are typically surprised as they observe children mastering complex concepts that they previously thought too difficult for young learners. Teacher boundaries of ZPD are then challenged as they learn to appreciate the greater capabilities of young children. A preschool teacher reflected, "I now see how I have been underestimating what my children are capable of. They don't always understand at the same rate, but given the right amount of guidance and encouragement as we use systems thinking strategies, I see my children's cognitive development growing before my eyes."

Moving from Discrete Events to Dynamics

Behavior-over-time graphs (BOTGs) provide a visual representation of the dynamics of a system, helping students practice one of the Habits of a Systems Thinker (Waters Foundation, 2010), "Observes how elements within systems change over time" (Figure 1 and Appendix A). Teachers often use "picture" books within literacy contexts as an entry point for helping students see change over time within a story. Initially, students tend to notice the individual events and can describe what happened first, second and so on. Teachers guide students to sequence these events along the x-axis of a graph to represent time in the story. They then consider how those events impact a particular variable on the y-axis, such as happiness, friendship or health.

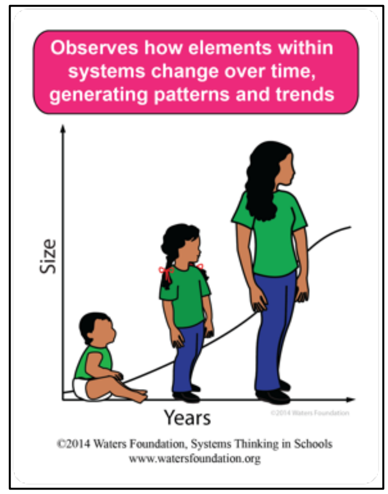


Figure 1: Change over Time

For the youngest students (3-4 years), some whom may be identified with developmental language and/or physical delays, it is important to build the understanding of dynamics through a scaffolding process, moving from kinesthetic experience to abstract concepts. For example, with the classic story, *The Gingerbread Man* (Mackinnon et al., 2007), students receive cut-outs of the main events and place them sequentially on a timeline (Figure 2). They then answer a series of yes/no questions, placing a "hand" along the timeline to indicate whether the gingerbread man had been caught. They draw a line connecting the hands to show the change over time.

Figure 2: ***The Gingerbread Man*** **Graph**

Figure 3: Magnet Graph

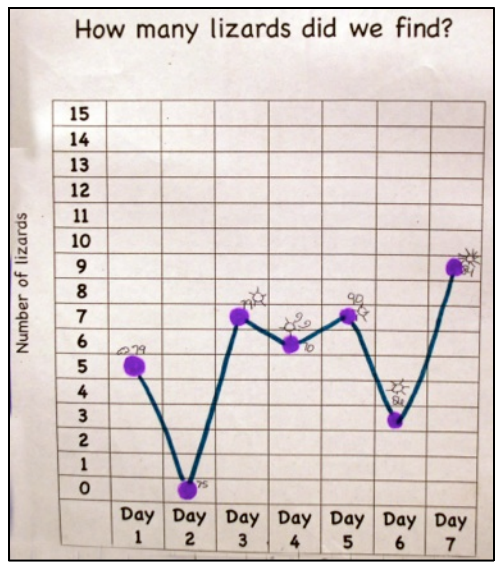


Figure 4: Lizard Graph

Another method is to have students use magnets on a cookie sheet to physically create a graph, placing the magnets on the individual points and then connecting them to see the overall trend (Figure 3). In another unit, preschool students go outside to observe whether or not they see any lizards. They indicate the days on the x-axis and their observations on the y-axis. They indicate that, “Yes, we saw lizards” or “No we didn’t see lizards” and track their responses in a similar manner. This type of 2-level graph is a precursor to identifying specific variables that are changing over time, e.g., the gingerbread man’s freedom or a population of lizards. As students’ understanding develops, they can track the lizards more precisely, using exact numbers on the y-axis for the lizards seen over time (Figure 4).

As students mature, teachers continue to build on this initial understanding. Students draw their own pictures to represent events and also see ways to define and label the y-axis with more precise understanding of what's accumulating, e.g., level of fear that ranges from feeling "paralyzed" at the highest point to "not afraid" at the lowest point. Eventually they create text-based explanations and define the time boundaries on the x-axis as more continuous (Figure 5).

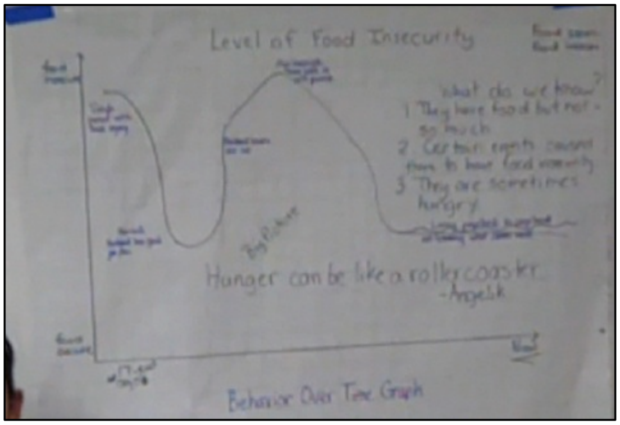


Figure 5: Food Insecurity

Still, it can take a while for students to move from representing the level of a variable as a series of connected dots to seeing the general pattern or trend over time and representing it as a smooth line. Teachers must also scaffold the concept of trend for students.

Trends: Identification and Naming

Many familiar children's books have similar patterns, based on a character's repeated attempts to solve a problem or achieve a goal, followed by the resolution or happy ending (Figure 6). In the folk tale *Abiyoyo* (Hays and Seeger, 1994), the villagers are constantly annoyed with the young boy and his father, that is, until they successfully rid the town of Abiyoyo, the monster that has plagued them forever. The common pattern of sad, sad, sad… happy, is repeated across many stories, such as *The Little Red Hen* (Miller, 2001), *Cinderella* (Dias and Disney, 2005), and many others.

Figure 6: *Abiyoyo* Graph

As teachers expose young children to multiple stories with similar structure, they can visually see the similarities as they create their BOTGs and thus have one more tool to develop inter-textual awareness, the ability to recognize stories that have similar patterns. As students increase their familiarity with these types of graphs they begin to notice similarities, sometimes even naming the pattern of the line. Students in one preschool class call an oscillating pattern a "crown story." A student looking at the graph of a crown story, *Goggles* (Keats, 1998), determined from the "points" that every time the character, Peter, took action he felt less afraid of the bigger boys that were chasing him (Figure 7). Other actions in the story caused his fear to go back up, until finally the story resolves and his fear diminishes in the end.

Over time, students begin labeling other "story lines" as well, comparing them to commonly known objects. A graph that goes up, plateaus and goes down is a "table story." The labels of classic trend lines (e.g. crown, mountain, table, smile, slide) enable children to recognize changes over time as patterns that they can rapidly refer to when reading new stories. As new stories are introduced, children more easily see the similarities to previously identified trends, predicting the pattern even before finishing the story. For example, when a teacher was reading a new story, a child exclaimed, "Ah, I think this could be a mountain story because the girl is getting more and more afraid, but I think she will be less scared at the end."

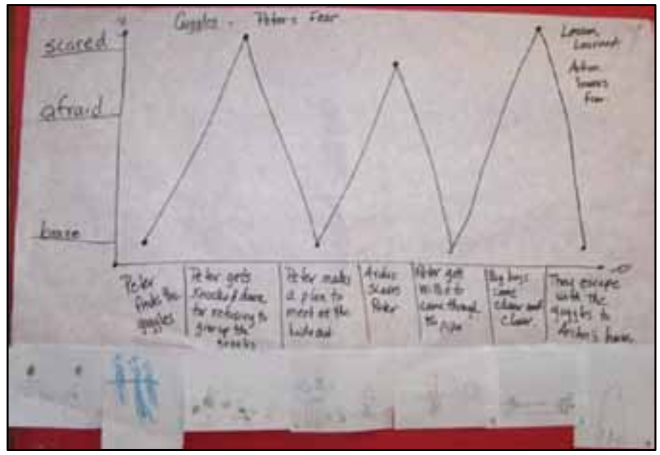


Figure 7: *Goggles*

After graphing a story, students can begin to see those trending variables as key accumulations in a story. But what does an accumulation really feel like? How can students experience an accumulation rather than just talk about it?

Accumulations and Rates of Flow: Moving from Kinesthetic Experiences to Abstract Representations

Teachers create spaces for their students to both observe tactile examples of accumulations and to represent the concept of an accumulation with their own bodies. When young children experience the sensations of sand and water as they pour, build and mix it, they are also building an initial understanding of accumulation, a basic concept of systems thinking (Figure 8) that also strongly ties to core curriculum math and science goals. When children have repeated experiences of pouring sand from one container to another, they learn to recognize when one container holds more, holds less or holds the same amount of sand. Piaget calls this the idea of conservation and believes that this ability does not develop in children until the concrete operational stage, which he generally considers to be between ages seven and eleven. An early childhood educator who gives students these kinesthetic experiences repeatedly and provides them with tools to record their observations is facilitating this development earlier. They are not "teaching" conservation, but rather building the capacity to observe, document and explain this phenomenon all in the context of common play-based experiences.

Figure 8: Accumulations

Eventually, preschoolers can move from playing with physical accumulations, like sand and water, to representing those and other accumulations using an abstract diagram of a stock and its related flows. A teacher may start building stock/flow maps with her class to represent a specific emotion of a character in a picture book. For example, in one preschool literacy lesson, the teacher guides the discussion of a book, *Rubia and the Three Osos* (Elya and Sweet, 2010), by having students suggest what increased and decreased the happiness of the main character over the course of the story. As students share elements, the teacher adds them to the map. In this case, the teacher also had a student help label some elements on the diagram (Figure 9).

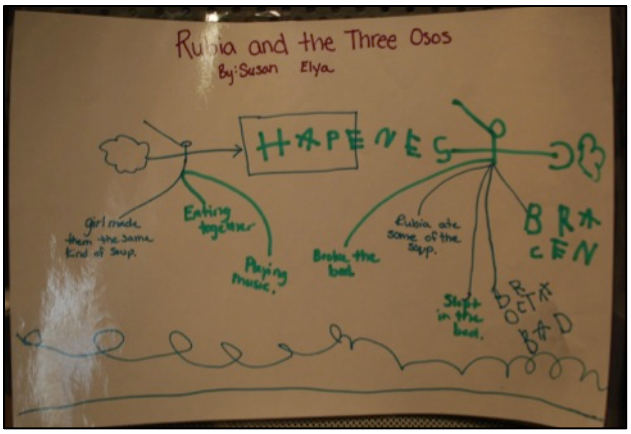


Figure 9: Happiness Stock/Flow

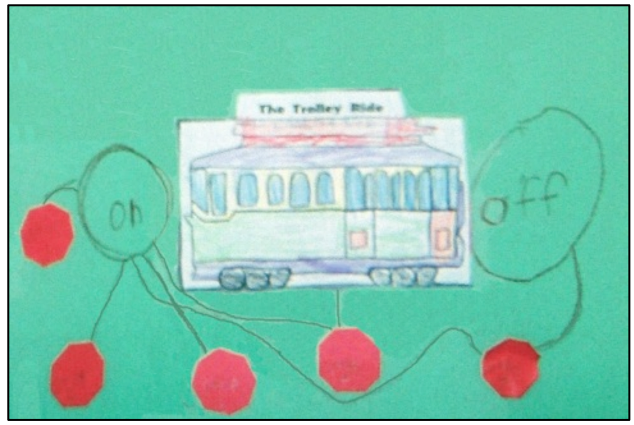


Figure 10: *Trolley Stock/Flow*

The process of creating the map provides students the opportunity to reflect on the main elements of the story and to bring those elements together into a visual representation of the whole. Within that creative process, having students focus on a seemingly abstract accumulation, such as a character's changing emotion, helps students relate that accumulation to their own emotions or to those of their peers.

In a kindergarten reading and math lesson, students are introduced to stock and flow thinking through a book that describes a physical accumulation, the number of passengers on a trolley. At each stop, a new passenger boards the trolley. At the last stop, a "monster" gets on, scaring off all the other passengers. Children retell the story by placing a figurine or counter in a box as each passenger gets on the trolley and then removes those figures when the monster gets on. This developmentally appropriate, play-based activity allows students to represent mathematical functions with objects, while adding verbal explanations. Students then create their own visual representations of the story using cutouts and drawings (Figure 10).

Figure 11: Zoo Game

Another method to develop the concepts of both accumulation and rate is to have students represent these elements by moving themselves in and out of a stock drawn on the classroom floor. Based on the “In and Out Game” in *The Shape of Change* (Quaden and Ticotsky, 2004), originally developed for elementary and middle school students, this version has students create their own rates of change for the stock, such as the number of people visiting the zoo on a particular day (Figure 11). Students represent visitors entering and leaving the zoo over time via a bi-flow, based on a schedule they develop. They track the total number of visitors at the zoo on a graph, connecting their observations to basic addition and subtraction skills, along with more abstract algebraic concepts involving rate of change.

Eventually, students can use smaller manipulatives to represent a stock, e.g., cotton balls, beans or blocks (Figure 12). As confidence and understanding build, students can begin creating their own stock/flow maps using the abstract icons to represent accumulations, flows and auxiliary variables (Figure 13).

Figure 12: Stamina Stock/Flow

Another way of introducing the concepts of stock and flow thinking to young children is with the use of a simple bathtub analogy. In teaching the basic principles of accumulation and its accompanying rates of flow to both adults and children it is helpful to think of a bathtub. Water enters the bathtub through the faucet. The more open the faucet, the faster the bathtub fills; however, if you don’t plug the drain you will never achieve a significant amount of water in the bathtub. Building on the common experience of taking a bath, first and second graders often further refine their understanding of stock/flow thinking by using a water bottle apparatus to model the concepts of accumulation and rates of change.

Figure 13: Garden Health

The book *The Water Hole* (Base, 2001), a counting book, tells the story of animals coming to drink from a water hole. As more and more animals make their way to the hole, the amount of water begins to decrease until it is completely gone. The animals leave, too, but eventually a rainstorm refills the water hole and the animals return.   After reading this story young students are able to retell the key dynamics of the story using the water apparatus (Figure 14).

Primary-age students experimenting with the apparatus deduce what happens to the amount of water in the bottle when the inflow is greater than the outflow, when the outflow exceeds the inflow and when the rates of inflow and outflow are the same. After some time of informal experimentation, students may perform challenges to understand the basic idea that the rate of inflow relative to the rate of outflow affects the amount of accumulation in the bottle. Specific challenge directions are attached (Appendix D).

Figure 14: ***The Water Hole***

"Mathematics educators need to appreciate young children's informal mathematics on entry to school--their versions of counting, adding, and subtracting, and understanding" (National Research Council, 2001). The type of developmentally appropriate play experienced through these stock/flow activities is critical for conceptual development; in addition, it can be directly linked to a progression in algebraic skills that begins in kindergarten. In kindergarten students are asked to "represent addition and subtraction with objects, fingers, mental images, drawings, sounds, acting out situations, verbal explanations, expressions or equations" (National Governors Association, 2010). In the context of a developmentally appropriate classroom, under the guidance of an intentional teacher, all play experiences that involve counting, accumulations, and the concept of more and less, prepare children to demonstrate mastery of mathematical standards.

Lillian Katz says that we often overestimate children academically and underestimate them intellectually (Katz, 2000). This series of activities, spanning both English language arts and mathematics, illustrates that by moving from kinesthetic experiences to more abstract representations students can indeed demonstrate an understanding of accumulations as well as rates of flow, while at the same time developing a solid foundation for more complex learning.

Survey Data Collected from a Sampling of Early Childhood and Primary School Educators

The Waters Foundation conducted research to document the impact of systems thinking instruction in early childhood classrooms. Teachers from five U.S. cites (Milwaukee, WI; St. Louis, MO; Tahoma, WA; Tucson, AZ; and Winston-Salem, NC) who have been actively involved with Waters Foundation systems thinking training and follow-up were surveyed. The survey included both Likert scale ratings and open-ended responses.

Number of respondents

18 (of approximately 40) preschool through third-grade teachers who were sent the survey link (Appendix B) responded. Teachers use multiple ST strategies across multiple subject areas, with many choosing to use these strategies for project-based or interdisciplinary units. More than half the respondents have implemented for three or more years.

Survey Data Collected

Below are the main survey questions along with the numerical responses. Appendix C shows the full survey responses, including all written examples.

1. To what degree was using ST strategies an effective way for your students to learn class material?
   - Average = 4.5
   - Standard Deviation = 0.71
   - Range = 2
2. To what degree do you think your students learned more by using ST strategies than they would have otherwise?
   - Average = 4.39
   - Standard Deviation = 0.70
   - Range = 2
3. How often have you noticed your students applying what they learned as part of schoolwork to their own life situations?
   - Average = 3.28
   - Standard Deviation = 0.83
   - Range = 3
4. In what ways have you gathered evidence of your students' learning while using ST strategies? See Table 2.

Table 2: Types of Assessments Used to Gather Evidence of Learning

Type (choose as many as are used)	Number of Respondents
Parent Observation	2/18
Portfolios	7/18
Pre-test and Post-test	4/18
Rubric Assessment	4/18
Self-assessment with Rubric	4/18
Teacher Observation	17/18

Analysis

Survey questions #1-3 had a range of 1-5 with 1 being not at all effective to 5 being highly effective. The range of responses was either 2 or 3, with the responses ranging from 2-5 or 3-5. No respondents selected a value of 1 for any of the questions.

The standard deviation indicates a tendency for teachers to be in high agreement with one another. Teachers tended to see very positive impacts on their students in general and in comparison to the use of other methods to teach the same content. In addition, individual comments made by teachers provide specific evidence of learning and an overall positive impact on students in their ability to learn and communicate understanding.

Questions 1 and 2
The average response for question 1 is 4.5, indicating an overall tendency for teachers to see ST strategies as an effective method for learning. Most respondents also saw the use of ST strategies as a more effective method for learning in comparison to other instructional methodologies (average response is 4.39).

Individual examples of how systems thinking strategies help in the development of cognitive capacities and increase engagement within their students can be convincing to an educator. In the survey responses, 100% of the stories gathered were positive learning examples, which indicates strong support for the use of ST strategies with young students. In addition, some general patterns emerge from the responses, which were gathered from teachers across the United States. Some of these are that an ST approach fosters an ability to:

- analyze data in novel situations, including academic and personal.
- see multiple perspectives while viewing a system.
- articulate cause and effect relationships.
- communicate thinking to others, both other students and adults.
- create comparisons of multiple systems.
- reflect and become more self-aware of emotions and thoughts.

In addition, a sense that teachers feel more empowered to engage and to teach students to think deeply is evident throughout.

Question 3

The average response for this question is 3.28, and although lower than questions 1 and 2, it is still significant. One of the strongest indicators of learning is when students can transfer understanding gained in one situation to a new situation with different characteristics or a different context. Almost all respondents were able to cite one or more examples of students who could make connections to other situations outside of the context of schoolwork. For example, a student might use a behavior-over-time graph when reading a story and later go on to independently create graphs to represent personal issues of concern. Some general areas in which students make connections include:

- habits, such as eating, exercise, TV usage.
- observations of natural systems at school and at home.
- personal happiness in and out of school.
- friendship and issues on the playground.

Question 4

Although teachers have a variety of methods for collecting evidence of learning, the respondents to this survey most often use observation and portfolios. Students using ST strategies are often creating visual representations of their learning, so these two methods are effective in measuring student ability to represent and communicate their understanding. Portfolios emphasize what students produce in terms of a physical product, while teacher observations focus on what students are doing and saying as they experience a particular strategy. Teachers look for specific evidence (or lack of evidence) that their students are gaining new understanding. Teachers noted evidence that their students were:

- using visual representations to improve reading skills, e.g., sequencing, retelling, inter-textual awareness.
- recreating representations independently.
- using systems language (concepts, tools, habits) routinely in classroom conversations.
- transferring to new units of study and/or to personal issues of concern.

Certainly, additional data will be useful in refining these results, however, this initial evidence illustrates some of the possibilities and potential for using these methodologies with the youngest students. A possible next step is to identify gaps in the data, given the survey responses, with a goal to create a revised survey that would more thoroughly assess all skills noted in Table 1.

Conclusion

There is adequate evidence both in the actual work of students and in the skillful observation and assessment of early childhood educators that building a systems thinking capacity in children ages three to eight, specifically through the development of stock and flow thinking, increases students' cognitive capacity and intellectual engagement. The tools give students a visual vehicle to express their thinking while the habits of a systems thinker build their conceptual understanding of dynamic systems.

This understanding of dynamic systems is important because it correlates directly to a variety of academic and intellectual skills typically developed in preK-12 education. This type of complex thinking supports conceptual development and problem solving in mathematics. It builds an understanding of text structure, essential to the comprehension of complex text in reading. The visual nature of the tools and the language of the habits improve a child's ability to communicate. It has long been known that young children have far more knowledge and understanding than their early levels of language enable them to communicate. Explicit, intentional instruction in systems thinking—through developing the capacity to make trends and accumulations visible and recognize the nature of dynamic systems—results in students who are better able to communicate their understanding to others.

The open-ended nature of systems thinking instruction also allows for students' ability to use these tools with flexibility and independence. The concepts of system dynamics do not limit young children to a single concept or topic of exploration but allow students to transfer their understandings from one system to another, increasing both the rate and depth of learning. This kind of teaching encourages students to reflect, predict and hypothesize. As a result, students take greater responsibility for and ownership of their own learning.

Appendix A – Habits of a Systems Thinker

Appendix B

Using Systems Thinking within Early Childhood/Primary Settings

This survey is intended to gather the experiences and perceptions about the impact of using ST strategies within early childhood settings. All items with an asterisk (*) are required to submit your response. Thanks much for sharing your experiences.

* Required

What do you teach? *

Select one or more of the options below.

- ☐ Pre-school
- ☐ Kindergarten
- ☐ 1st Grade
- ☐ 2nd Grade
- ☐ 3rd Grade
- ☐ Other: ______

Approximately for how long have you been implementing ST strategies with students? *

- ○ Less than 1 year
- ○ 1-2 years
- ○ 3-5 years
- ○ More than 5 years

School Name *

______

Name (optional)

______

Which of the following have you used with your students? *

Check as many as apply.

- ☐ Habits of a Systems Thinker
- ☐ Behavior-over-time Graphs
- ☐ Causal Loops
- ☐ Stock/flow maps
- ☐ Computer Models or Simulations
- ☐ Ladder of Inference
- ☐ Iceberg Visual
- ☐ Archetypes
- ☐ Other: ______

In what areas have you implement systems thinking strategies? *

Check as many as apply.

- ☐ Art/Music
- ☐ Classroom Community/Management
- ☐ Math
- ☐ PE/Health
- ☐ Project-based learning / Interdisciplinary
- ☐ Reading
- ☐ Science
- ☐ Social Studies
- ☐ Goal-setting or tracking learning processes
- ☐ Writing
- ☐ Other: ____________

To what degree was using ST strategies an effective way for your students to learn class material? *

	1	2	3	4	5	
Not at all effective	○	○	○	○	○	Highly effective

What is an example of this?

____

To what degree do you think your students learned more by using ST strategies than they would have otherwise? *

	1	2	3	4	5	
My students learned less than they have with other methods.	○	○	○	○	○	My students learned significantly more than they have with other methods.

How often have you noticed your students applying what they learned as part of school work to their own life situations? *

	1	2	3	4	5	
Never	○	○	○	○	○	Frequently

What is an example of this?

How often have noticed your students mentioning ST habits and tools independently (not a part of a lesson)? *

	1	2	3	4	5	
Never	○	○	○	○	○	Frequently

In what ways have you gathered evidence of your students learning while using ST strategies? *

Check as many as apply.

- ☐ Pre-test and post-test
- ☐ Parent Observation
- ☐ Portfolios
- ☐ Rubric assessment
- ☐ Self-assessment with rubric
- ☐ Teacher Observation
- ☐ Other:

What is one story you can share as an example of student learning?

Appendix C

Survey Responses: General Questions

(Note: number of respondents in parentheses)

What do you teach? (Note: Some respondents selected more than one grade.)

- Preschool (4)
- Kindergarten (3)
- First (6)
- Second (4)
- Third (4)
- Other (1)

Approximately how long have you been implementing ST strategies with students?

- Less than 1 (1)
- 1-2 years (4)
- 3-5 years (5)
- more than 5 years (3)

Which of the following have you used with your students?

- Habits of a Systems Thinker (10)
- Behavior-over-time Graphs (18)
- Causal Loops (13)
- Stock/flow Maps (14)
- Computer Models or Simulations (4)
- Ladder of Inference (10)
- Iceberg Visual (6)
- Archetypes (3)
- Other (1)

In what areas have you implemented ST strategies?

- Art/Music (2)
- Classroom Community/Management (14)
- Math (8)
- PE/Health (1)
- Project-based Learning/Interdisciplinary (9)
- Reading (17)
- Science (12)
- Social Studies (10)
- Goal-setting or Tracking Learning Processes (6)
- Writing (5)
- Other (0)

Survey Responses: Use of ST Strategies as a Methodology

Question (ranges from 1-never to 5-frequently)	Examples
To what degree was using ST strategies an effective way for your students to learn class material? Average = 4.5 Standard Deviation = 0.71 Range = 2	**Preschool** ● “I have done a lot of work using BOTGs to analyze and interpret emotions of characters. Thinking about another person/character's emotions is very difficult for preschoolers. After creating graphs, as well as stock-flow diagrams, I noticed students were more in touch with each other’s feelings. They began to really think about the causes for different feelings.” ● “In the area of literacy, the children are able to analyze the perspective of different characters and develop an understanding for the changes in the characters' behaviors. When examining the different perspectives of the characters, the children are able to safely explore various emotions and causes for those emotions. Through the use of ST tools, the students are not only listening to the words in the story but also using the illustrations to understand and make inferences to support their thinking. The children often use the ST tools to retell and share their understanding of the story we read with their parents at pick up time. The visual nature of the tools is a perfect fit to assisting the children in sharing their thinking process independently.” **K-1st Grade** ● “At the beginning of the year I do a BOTG graph on our learning during the day, with low, medium and high. I do it the first day of school and … then they can do [it] the rest of the year! I usually start the discussion with the 2 class leaders.” ● “My students were instantly able to understand a story better through the use of a causal loop. They then could transfer this system to other stories as they recognized it.” ● “The greatest benefit is the development of the ability to think in systems, to be aware of how one's actions (or inactivity!) lead[s] to consequences, whether intended or not, positive or negative.” ● “One of the most satisfying current examples is a project my students have underway, where they noticed it was cold in the hallways, noticed large gaps under exterior doors, worked on gathering data and interpreting it. They are now facile with providing consequences: if it's cold in the winter, it will be hot in the summer. If it's cold, the heaters will run more. More electricity. More cost. Gaps = ability of "critters" to enter the building. ETC! (You might argue that this is not class material, but it is "material" to me to build problem solving skills, grit, flexibility in thinking, etc.)” ● “Behavior over time graphs to visually represent change over time, stock flow charts to visually represent the whole picture of a system/situation” ● "My first graders were able to verbalize cause and effect relationships when talking about social/emotional situations like escalating emotions on the playground. Systems thinking gave them language to explain these situations. When using BOTGs while discussing literature, students were more likely to use evidence to explain their thinking. When a student disagreed about a claim made by another student (ex: I don't think the character changed like that), students were more likely to use evidence and have productive/fact-based arguments.” **2nd-3rd Grade** ● “I use the stock flow chart when we talk about the behavior we want in our classroom and when the students are in specials.” [e.g., art, music, p.e.] ● “Using the ladder of inference to understand character's actions and/or motivation.” ● “Using Behavior over Time Graphs to understand the movement of molecules in

Question (ranges from 1-never to 5-frequently)	Examples
	solids, liquids, and gasses." ● "Since the ST tools are very visual, it gives the students a new avenue to understand and communicate new material to one another. For example, I like to use the Habits to discuss Reading Comprehension strategies. Using the mental models habit, I can offer students ways to compare and contrast characters in a story." ● "Students are gathering more strategies in terms of how to regulate themselves in their learning but also how to explain their thinking during literacy." **Multiple Grades** ● "My students use BOTGs when retelling stories or for planning their own written stories. When writing, they have learned that there needs to be some kind of change in the story for it to be interesting. On the bottom of the BOTG the students draw pictures and/or plan the beginning, middle, and end of their story. They then have to identify and explain to me or a peer at least one change that happens in their story before going on to the writing stage. The students are always looking for change and patterns that occur when listening, reading, and/or writing a story." ● "The iceberg model has been used often for multiple content areas. It serves as a great visual to help my students explain their thinking and reasoning."
To what degree do you think your students learned more by using ST strategies than they would have otherwise? Average = 4.39 Standard Deviation = 0.70 Range = 2	Note: This question only has numerical data.
How often have you noticed your students applying what they learned as part of schoolwork to their own life situations? Average = 3.28 Standard Deviation = 0.83 Range = 3	**Preschool** ● "When I was in a classroom where I was able to use Systems Thinking often, I saw children using the graphs within their play. Here is a specific example: One child was looking at our class pet, a leopard gecko, and made a BOTG about how often the gecko came out of her cave." ● "During the beginning of the school year, we create a Stock/Flow diagram on our own happiness. We wrote happiness as the stock and added to the diagram what contributes to our happiness and what takes away from our happiness at school. The Stock/Flow was posted in the classroom and referenced when conflicts [arose]. One day, a girl in the class came to the teacher for assistance with a social problem. The child explained to the teacher what was going on and concluded with stating, "it is taking away from my happiness." **K-1st Grade** ● "After they use the graph I hear them use the language of the graph; an

Question (ranges from 1-never to 5-frequently)	Examples
	example— “That science log is high level learning!” ● “I had one student try to explain that he was going to be sitting next to certain students at lunch in a reinforcing loop because he was doing Kid A, Kid B, Kid A, Kid B. Clearly not the correct use...but he recognized a similar pattern in his own life!” ● "A precious current example: a student was saying how the more he & his parents paid attention to their baby, the cuter the baby seemed. Then the cuter the baby seems, the more they want to pay attention to him. A classmate helped to construct a causal loop.” ● “We are making a light & sound show in science. Students are constructing musical instruments that demonstrate variability in pitch and volume, and many of them cited using recycled materials as having less impact on the world than using previously unused material would.” ● “Beginning with rudimentary use of BOTGs in reading response, students have now gone deeper, working to identify, understand, and communicate the interdependent nature of character's thinking: actions." ● “will independently create a BOTG or stock flow to represent something they are curious about or interested in” ● Students would use cause and effect language (and thumbs to demonstrate increase/decrease) to describe playground issues and their thinking about literature. **2nd-3rd Grade** ● “using behavior[-over-]time graphs to track eating/exercise habits... yes! 3rd graders!” ● “I had a student [who] kept a personal journal of BOTGs that she created at home. She noticed trends and changes over time in her house, and she graphed them (example: TV usage).” ● “Students often refer to the tools or habits to explain situations they find themselves in.” ● “Students are beginning to think about the habits and how that [affects] their lives and choices they make” **Multiple Grades** ● “Student initiated BOTGS at home in regards to likes and dislikes of trying new foods, excitement about home celebrations” ● "Many of my students have experienced friendship issues and changes in friends that happen. They have been able to use BOTGs to see patterns/changes and discovered what might have been causing those changes in their friendships.” ● “My students also have used BOTGs to help understand/explain what helps them learn and what distracts them from learning. This opens up conversations about what behaviors can help them stay focused and learn.”

Survey Responses: Types of Assessments Used to Gather Evidence of Learning

Type (choose as many as are used)	Number of Respondents
Parent Observation	2/18
Portfolios	7/18
Pre-test and Post-test	4/18
Rubric Assessment	4/18
Self-assessment with Rubric	4/18
Teacher Observation	17/18

Evidence of Student Learning Given by Teachers

Preschool

- "I was teaching a herpetology class. Once a week I took students out to count the lizards and snakes that we saw and mark them on a BOTG. During that class I had a herpetologist from the U of A come to work with the kids. He happened to show them a behavior over time graph of his research. I was so proud when my 4 & 5 year olds were able to analyze his graph."
- "One day, a child asked to take the BOTG we created at story time to the writing table. The teacher handed the BOTG to her and observed what happened next. The child went to the table, and proceeded to create a replication of the BOTG on her own piece of paper. When the teacher inquired as to what she was doing, she stated, "I want to make the graph so I can take it home and tell my daddy about the story." Her mother was the one to drop her off and pick her up from school each day, so she had not been able to share prior BOTGs with her dad like she had with her mom at pick up time."

K-1st Grade

- "We start the year learning about realism and fantasy stories. This is such an easy way to learn this skill with a visual BOTG. I put some of the pictures from the story on the graph and then we decide what is real about the story and what is fantasy. It can be a simple thing to use and so effective for those low learners!"
- "The story structure archetype and the reinforcing loop have been most effective when we dig into stories. They are able to sequence better with these systems [tools] and it increases their understanding."
- "Just one detour back up to the question of how often I've noticed students mentioning ST habits/tools: sometimes, things become such a matter of routine that they are unremarkable."
- "At the beginning of this school year my students launched a project involving problems with a drinking fountain. Over time, they decided that a water bottle filling fountain would be a great solution. Having gained the support of our district's facilities director, the principal next came to us to ask about its installation. At that moment, [there] was instant conversation regarding best placement, and the final decision was to locate it where it would be [most] accessible by all students, and additionally where it would not cause interference with our normal routines. Independent application is the best demonstration of learning!"
- "Using a BOTG to investigate the plot of various literature and then applying what they have learned to write their own stories with BOTGs."

- "Using systems-thinking strategies has made me a more engaged teacher and has helped motivate me through my own insecurities and my worries about below grade-level students making progress.
  I remember watching two students (both of whom struggled with decoding and writing) build a connection circle as they discussed the book *Mr. Tiger Goes Wild*. Their depth of thinking, ability to argue in a positive way about text details, and confidence in their ability to do well was amazing.
  I feel like these strategies allowed me to teach deep, critical thinking skills in a way that allowed below grade-level readers/writers and above grade-level readers/writers to engage with content on more equal footing. As I would watch students with low decoding and writing skills become excited/motivated, my own excitement and motivation to teach would increase."

2nd-3rd Grade

- "Having a student explain thoughts behind a BOTG. I thought the student was 'wrong' or 'missing the point' but as he explained why he made the graph the way he did, I realized he had a deeper understanding of the concept. He actually added a small nuance that I had not considered."
- "When my students entered the third grade, a teacher noticed that a former student of mine created a stock and flow to help answer a question on a standardized test. This shows me that the information transferred from grade to grade, and that the tools can be utilized in many situations."
- "Students did the in/out game to reinforce the concept of stock/flows. Students were highly engaged during the lesson. Students participated in high-level thinking, discussion, and even healthy debate as they participated in the simulation."

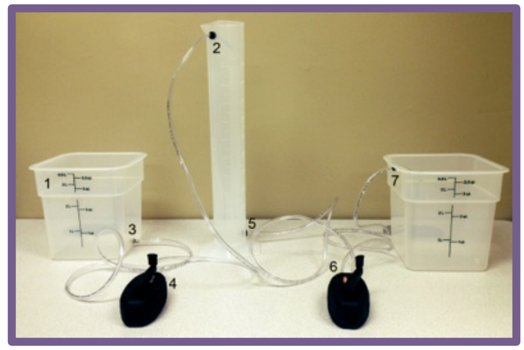
Multiple Grades

- "My students can verbally and through writing better explain their thinking and reasoning. The visual tools [aid] in explaining for those students lacking vocabulary and language."

Appendix D

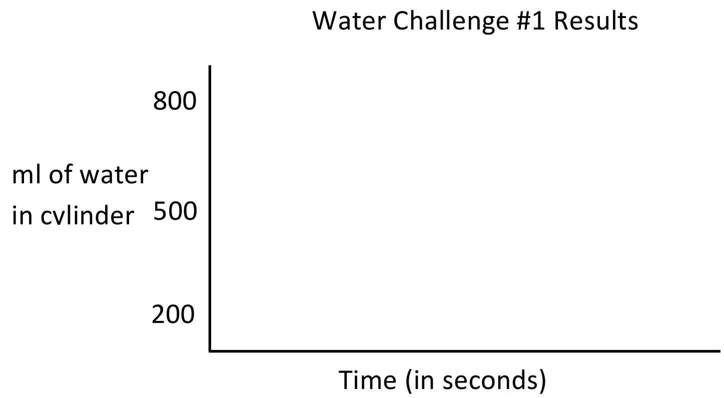
Water Challenges

For each challenge, start with all the *extra* water in the inflow "cloud." Before beginning, graph the goal (what the water should do over time). Then, graph what actually happens in a different color. After completing a challenge, continue with the next one. Feel free to repeat any challenge to improve results.



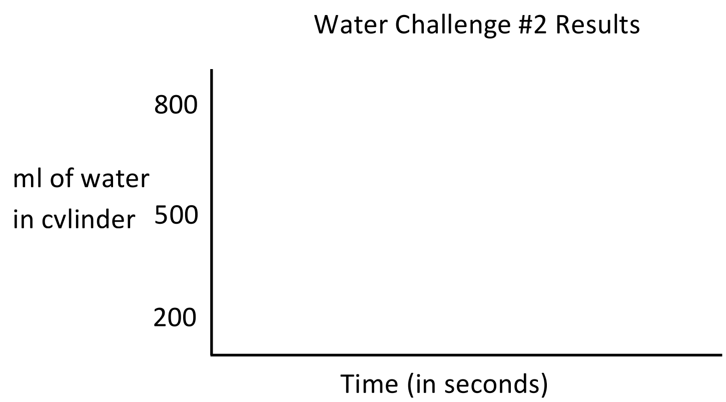
Challenge #1

Start with 200 ml of water in the cylinder, then raise the water from 200 ml to 800 ml while water is always going in and always going out.



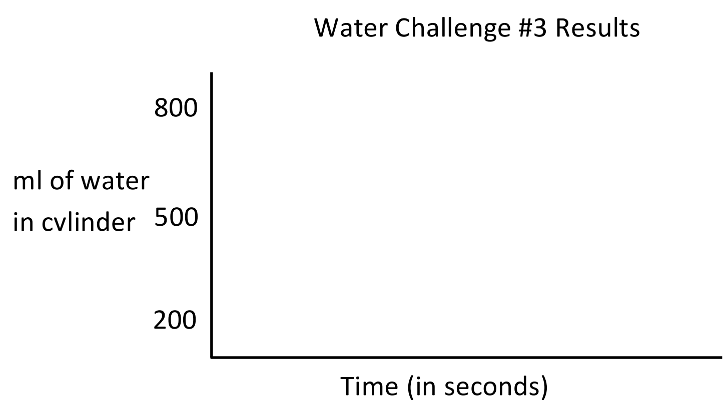
Challenge #2

Start with 800 ml of water in the cylinder, then lower the water from 800 to 200 ml, while water is always going in and always going out.



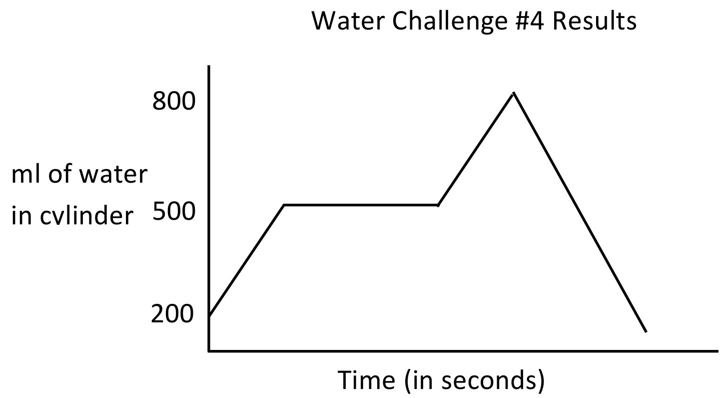
Challenge #3

Start with 500 ml of water in the cylinder, then keep the water at the 500 ml level for at least 30 seconds, while water is always going in and always going out.

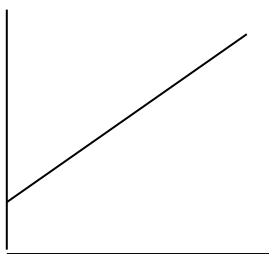


Challenge #4

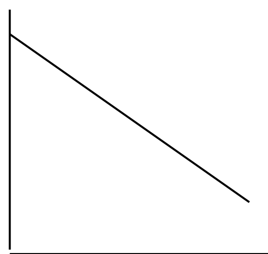
Create the water level shown on the graph while water is always going in and always going out.



Reflection: Match the graph to the description.



A



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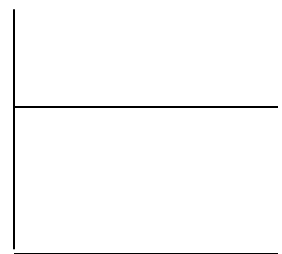


C

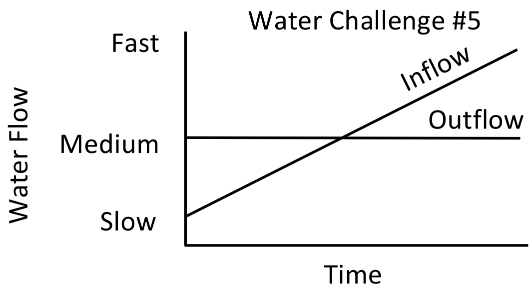
1. Inflow < Outflow
Graph ________ describes this situation because

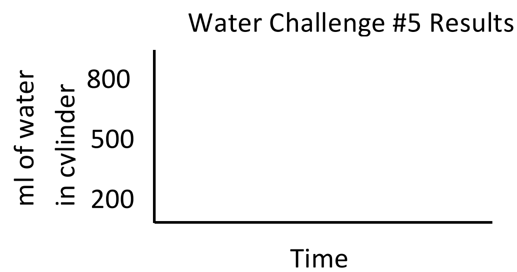
2. Inflow > Outflow
Graph ________ describes this situation because

3. Inflow = Outflow
Graph ________ describes this situation because

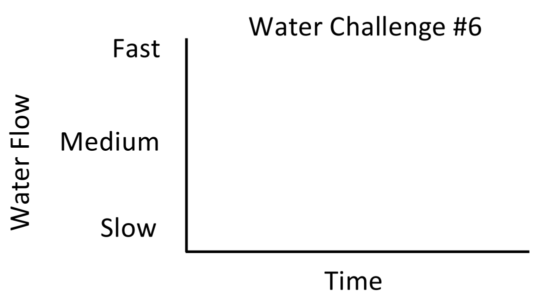
Challenge #5

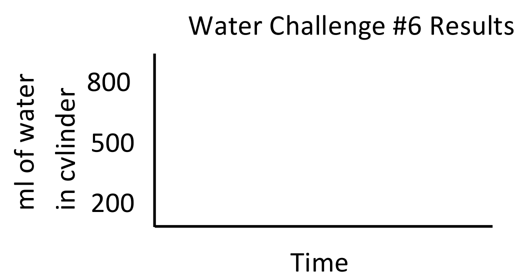
Start with 500 ml in the cylinder. Predict on the graph: What will happen if you adjust the inflow and outflow as shown? Notice the outflow stays the same while the inflow starts at slow and gets faster over time. Use the graph on the right to predict and then record what actually happens over time.





Challenge # 6: Create your own challenge
Create a challenge similar to #5 that graphs what you will do with the flows and predict what will happen to the stock. Make sure to label the inflow and outflow lines.





Reflection: Consider that the water in the cylinder is a stock and the water going in and out are flows. What else in your experience is similar to the stock of water? How do the flows work in that system?

References

Base, Graeme (2001). *The Water Hole.* Harry N. Abrams; First Edition edition.

Bowman, B.T., Donovan, M.S., & Burns, M. S. ed. (2001). *Eager to Learn*. Washington DC: National Academy Press.

Brown, Chris and Newell, Barry, ANU. Original water apparatus design. Modified with permission for water challenges. 2014.

Elya, Susan Middleton and Sweet, Melissa (2010). *Rubia and the Three Osas.* Disney-Hyperion.

Copple, C. and Bredekamp, S. eds. (2009). *Developmentally appropriate practice in early childhood programs serving children from birth through age 8* (3rd ed.). Washington: NAEYC.

Dias, Ron and Disney, RH (2005). *Cinderella.* Golden Books, English Language edition.

Galinsky, E (2010) *Mind in the Making: The seven essential life skills every child needs*, Harper Collins: NY.

Hays, Michael and Seeger, Pete (1994). *Abiyoyo*, Aladdin Paperbacks.

Katz, L.G., and Chard S.C. (2000). *Engaging children's minds: A project approach*. Stamford, Connecticut: Ablex Publishing Corporation

Keats, Jack Ezra (1998). *Goggles.* Puffin Books, Reprint edition.

Mackinnon et al. (2007). *The Gingerbread Man.* Usborne Pub Ltd.

Miller, J.P., Illustrator (2001). *The Little Red Hen*. Golden Books, English Language edition.

National Governors Association Center for Best Practices & Council of Chief State School Officers. (2010). *Common core state standards*. Washington, DC: Authors.

National Research Council (2001). *Eager to learn: Educating our preschoolers*. Committee on Early Childhood Pedagogy. Barbara T. Bowman, M. Suzanne Donovan, and M. Susan Burns, editors. Commission on Behavioral and Social Sciences and Education. Washington, DC: National Academy Press.

Quaden, Rob and Ticotsky, Alan (2004). *The Shape of Change.* Creative Learning Exchange.

Sykes, M. (2014). *Doing the Right Thing for Children: Eight Leadership Qualities of Leadership.* RSt. Paul, MN: Redleaf Press.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Waters Foundation (2010, 2014). Habits of a Systems Thinker. Waters Foundation.

Wood, D., Bruner, J., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Child Psychiatry*, 17, 89−100.

Wood, D., & Middleton, D. (1975). A study of assisted problem-solving. *British Journal of Psychology*, 66(2), 181−191.