Technological and Engineering Design Based Learning: Promoting Upper Elementary Graphical Device Comprehension

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Research Motivation

- Developing Disciplinary Literacy – Significance of Reading
  - Learning to read discipline-specific texts calls for instruction specific to that discipline
  - Contextual interpretation of discipline-specific text critical to constructing concepts
  - Instruction must provide experiences engaging students in the disciplinary language
  - Students afforded limited opportunities to engage with informational text
  - Barrier to comprehending informational text are experiences using *graphical devices*
- T/E Design Based Learning – Graphical Device Comprehension
  - Language of technology and engineering: sketches, diagrams, graphs, models, etc.
  - Such graphical devices:
    - *are intrinsic to disciplinary practices of technology and engineering*
    - *play a strong role in the teaching and learning of disciplines*
  - T/E DBL Potential: engage students in authentic T/E design practices to promote GDC

Research Motivation

- Research Gaps
  - Evidencing:
    - the efficacy of T/E Design Based Learning to teach other disciplines
    - that engaging students in authentic design challenges inclusive of graphical devices promotes discipline-specific reading comprehension
    - that teaching students designerly ways of knowing promotes disciplinary knowledge transfer

Graphical Devices

- Defined:
  - Used to convey new information or reinforce information from the continuous text
  - Organized in eight metacatagories:
    - Diagrams, Flow diagrams, Graphs, Timelines, Maps, Tables, Images, Simple Photographs
  - 60% of graphics contain information not found in written text
- Comprehension:
  - 6% of the total reading time spent examining visual elements of text (Hannus & Hyona, 1999)
  - 27% of the time students were looking at a graphic "they were not thinking about anything" (Norman & Roberts, 2015, p, 49)
  - Placement of graphical devices requires readers to interpret the text in a "nonlinear, nonsquential" manner (Gill, 2009, p. 266)

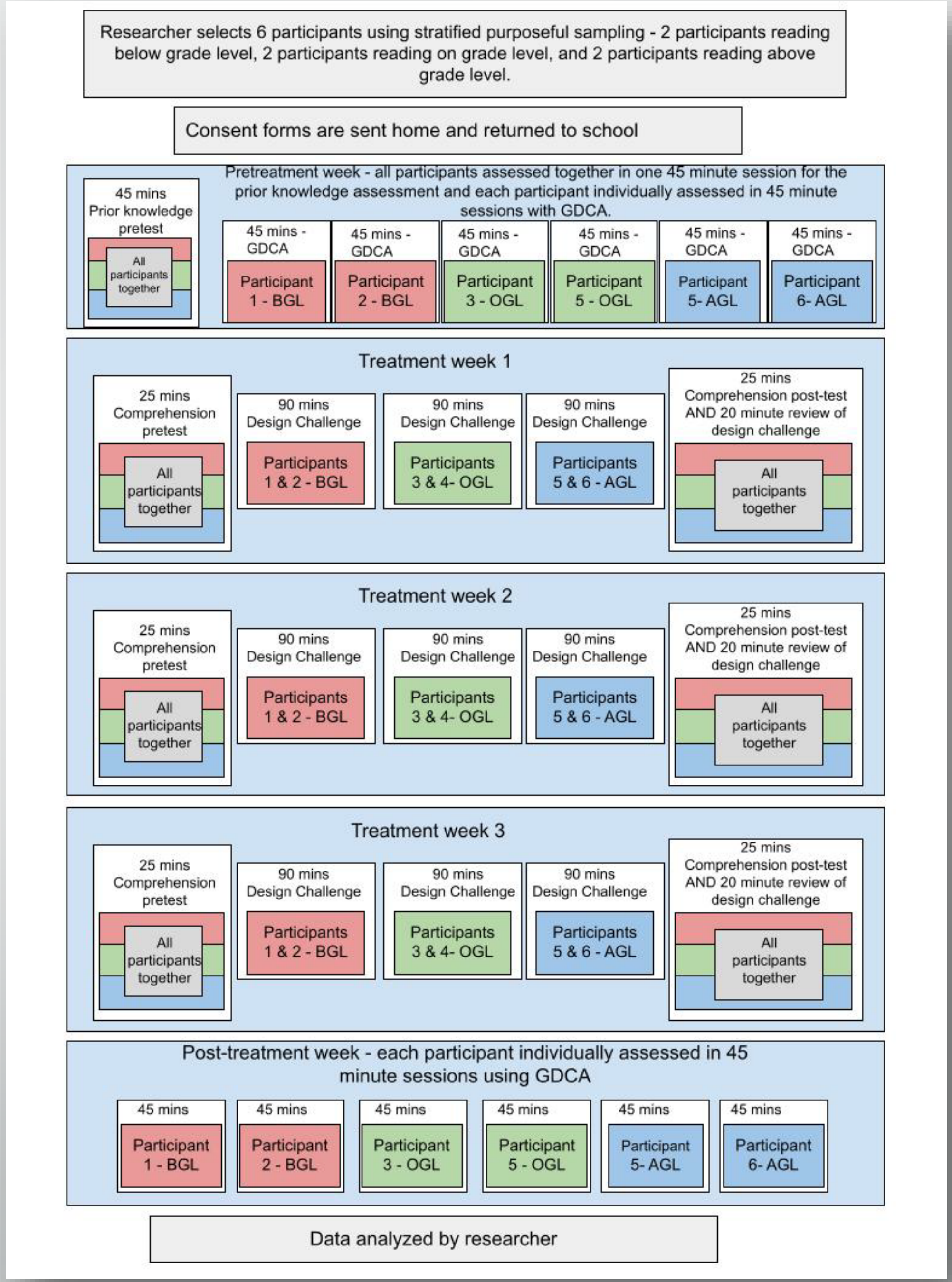
Research Problem

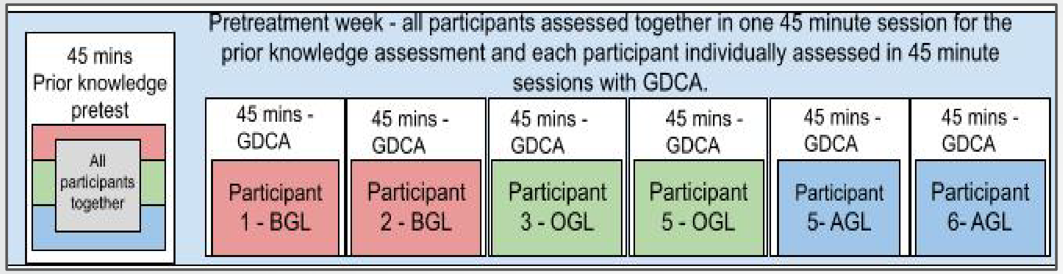
- **Significant Challenges:**
  - Student use and comprehension of graphical devices in nonfiction/informational texts
- **Graphical Device Comprehension (GDC):**
  - Important for overall comprehension of nonfiction/informational texts
- **Research Gap:**
  - Instructional strategies found to improve GDC at the elementary level
- **Present Study:**
  - Investigation of relationships between GDC comprehension and T/E DBL challenges incorporated into reading instruction.
- **Research Question:**
  - What relationship exists between design-based learning challenges which are supported by discipline-specific graphical devices and students':
    - Frequency of use of discipline-specific devices
    - Comprehension of science and engineering discipline-specific graphical devices in texts which are used to support the design-based learning challenge, and
    - Comprehension of science and engineering discipline-specific graphical devices in novel texts?

Participants

- Six participants selected using stratified purposeful sampling.
  - Determine the two on grade level participants by selecting the two students reading at level S (District determined grade level reading level) who have an SOL score at, or closest to the mean SOL score for that group of students
  - Determine the two below grade level participants by averaging the numeric equivalent of the reading levels for all students below level S (19) and selecting students at the mean reading level for below grade level readers. Of those students at the mean, students were ordered by SOL score and those at or closest to the mean SOL score of students below level S were selected for the below grade level stratum.
  - The participants for the above grade level stratum were selected using a similar process to the below grade level stratum. For the above grade level stratum, all students scoring about level S (19) were used to determine the mean reading level of that group.

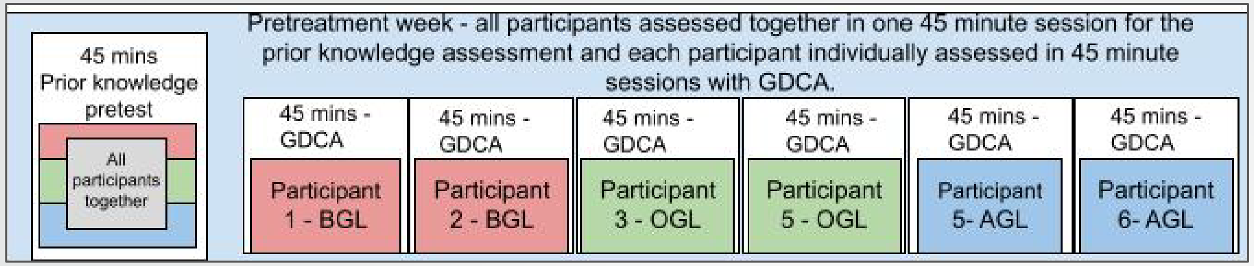
Implementation Schedule





Prior Knowledge Assessment

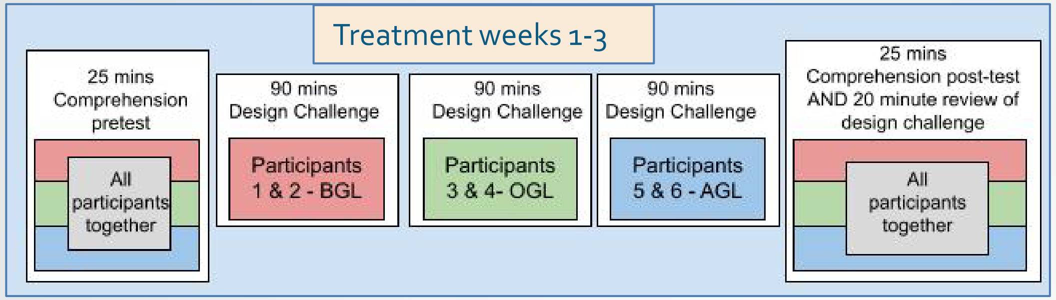
- Modeled after prior knowledge assessment rubric (Taboada, Tonks, Wigfield, & Guthrie, 2009)
  - Participants responded to an open-ended prompt asking them to write what they know about a specific topic.
  - Responses scored using a six-level rubric.
    - Lower levels on rubric equivalent to lower level answers (inclusive of minimal or inaccurate information)
    - Higher levels include more accurate information organized in relation to a set of nine, pre-defined ecological concepts



Graphical Device Comprehension Assessment

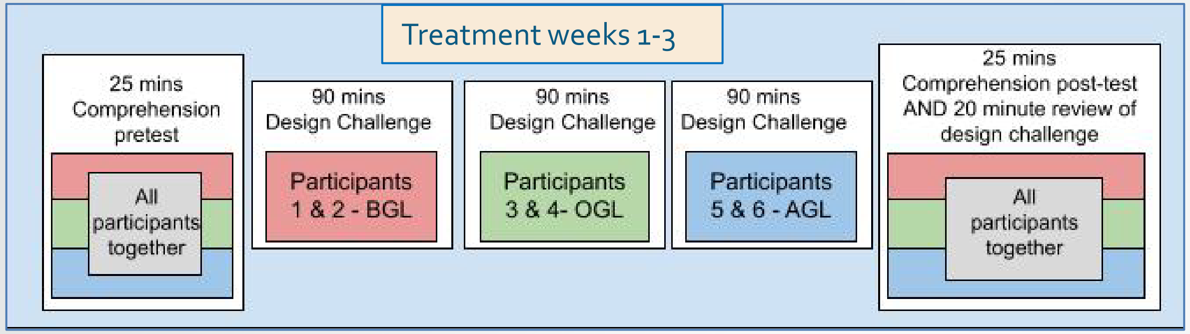
(GDCA, Roberts, Norman, & Cocco, 2015)

- Instrument to assess "students' understanding and interpretation of various graphical devices found in children's books"
  - Students shown graphical devices in authentic texts and asked questions about the information presented in the devices
  - Each question scored out of 2 points, totaled, and then converted to a scaled score
  - Engineering texts not included in original study
  - Engineering is the authentic context for multiple graphical devices so the assessment was adapted to include engineering texts



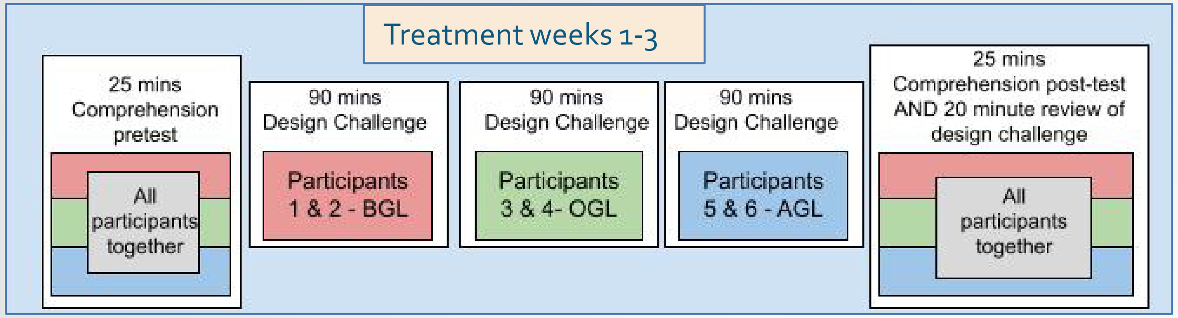
Reading Comprehension Assessment

- The reading comprehension assessment was developed based on a modification of the assessment method used by Taboada, Tonks, Wigfield, and Guthrie where participants were asked to read content specific passages and then respond in writing to an open-ended prompt.
- Scored using 6 level rubrics very similar to the Prior Knowledge Assessment



Frequency Observation Rubric

- The frequency observation rubric was a researcher-designed instrument used to record the frequency at which participants referenced a given graphical device during engagement in a DBL challenge.
- The frequency observation rubric was designed to account for all possible ways the participants might refer to the passages: visually only, orally, physically, in response to their partner, or in response to the researcher.
- The frequency observations of the text references were separated into two phases, initial design and design iteration, resulting in a total of 10 frequency categories.



T/E Design Based Learning Challenges

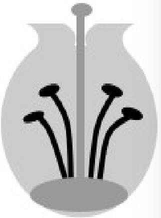
- Challenges incorporate both science and engineering concepts that are included in the texts for the comprehension assessment
- Criteria for the challenges are written to benefit from information contained solely in the graphical devices that are included in the comprehension assessment texts
- Challenges are **Design-No-Make** (DNM) where participants complete a design to solve the problem, but do not build it
- Participants work in reading level dyads

Design Briefs - DNM

Design Brief: **Hand Pollinator**

Background Knowledge: The bee population has gotten smaller over the years because humans have been taking over their habitats. Because of this, sometimes people are forced to hand pollinate their flowers in order to get the fruits or vegetables they are trying to grow. This is a problem that many scientists and engineers are working on solving right now with many different types of solutions. There are big designs that are working to pollinate whole fields of crops, and smaller designs that are working to help small gardeners. Farmers working to pollinate large fields may have more money to spend on a bigger, fancier design but the less time to spend on the pollination of the flowers. It needs to be fast. Gardeners worki small greenhouse of plants would have less money to spend so they would need a simpl but they could take a little more time on using the pollinator. The crops we are going to for this challenge are blueberries, which are almost 90% pollinated by bees. This is wha blueberry flower looks like:

https://commons.wikimedia.org/wiki/File:Shiny_blueberry_(Vaccinium_myrsinites)_(7154743184).jpg



Inside a blueberry flower

You can see that it is small (think about the size of a blueberry) and it has a small openi bottom of the ball-shaped flower.

Driving Question: How can we, as agricultural engineers, best design a hand pollinato pollinate blueberries at either a large farm or a small greenhouse?

Today's goal: Create a drawing of your plan for a blueberry hand pollinator. While yo have materials that you can use to help you problem-solve when making your plan, yo NOT be building a model of your package today. You may include some ideas for (dig technology or computers if you choose, but it should not be brand-new technology you never seen before. You can take something you have seen and change it to help with p

Criteria:

- ❑ Your plan includes a drawing of your hand pollinator
- ❑ Your plan states whether your pollinator is for a large farm or a small greenhou
- ❑ Your plan has each of the parts of your hand pollinator clearly labeled
  - ❑ Your plan has each of the materials that your hand pollinator is made o clearly labeled
- ❑ Your plan explains how the pollinator works - how does it do the job of the mi
  - ❑ This includes the parts of a flower needed to pollinate
- ❑ Your plan answers the questions:
  - ❑ Why did I select these materials for my hand pollinator?
  - ❑ What is a major challenge for your pollinator?

Resources:

- Pencils
- Paper
- Objects to help plan out your design - you are not limited to these mater your plan. These materials are just to help you problem-solve when crea plan.
  - Plastic eggs (with holes on one end)
  - Glitter
  - Paintbrushes
  - Tissue paper
  - Poms of different sizes
  - K'nex
  - syringes
- The passages of information

Flowers and Pollination Passage Comprehension Assessment

(When scoring: the examples provided are single sentences, however ideas and concepts may be provided by the student in multiple sentences. They may be scattered throughout the response. Also, if you are unsure if a fact is from the same source [text or graphical device] or different because it is located in two places, default to different. Prior knowledge is included if scorer has a question about whether information was taken from the passage or from the reader's head)

Level 1: Facts and associations – simple. Students present a few characteristics of flowers or pollination taken directly from text only. Facts can be isolated, with little connectedness to an overall idea. *(ex -The anther makes pollen.)*

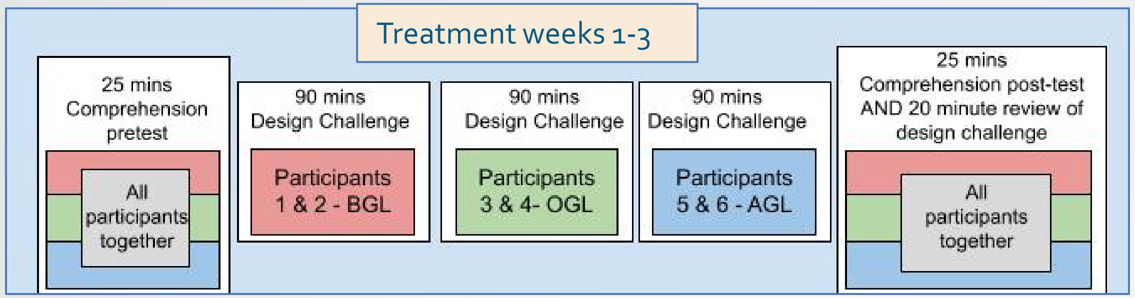
Level 2: Facts and associations – extended. Students present characteristics related to flowers or pollination as they contribute to an overall idea or process directly from text only. *(ex -Pollen sticks to an animal. The animal moves the pollen to another flower.)*

Level 3: Concepts and evidence – simple. Students demonstrate basic conceptual understandings of pollination by describing pollination using minimal evidence from both the text and one graphical device. *(ex - Flowers have colorful petals to attract animals. The animals move the pollen to another flower. OR The banana flower is pollinated when bats fly around the stamen at night.)*

Level 4: Concepts and evidence – extended. Students demonstrate a more advanced conceptual understanding of pollination by describing pollination using evidence from both the text and both graphical devices. *(ex. - The stamen and anther make the pollen. The pollen of a trumpet flower would be harder to get to than the daisy.)*

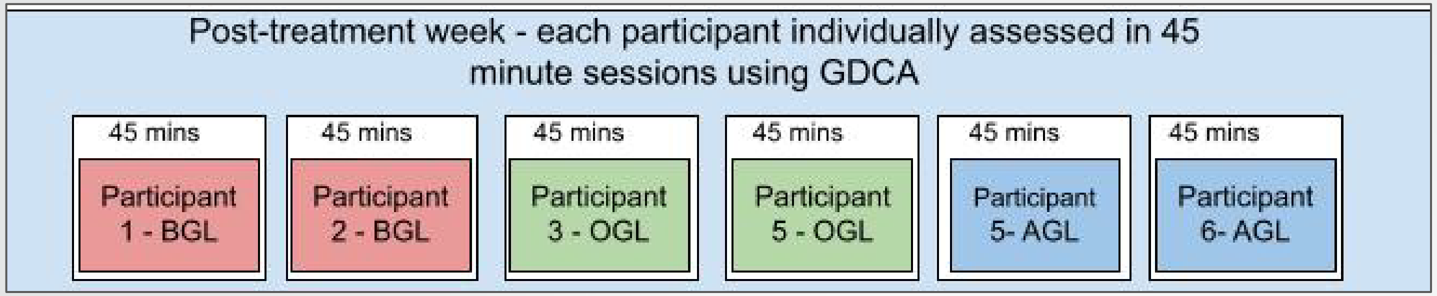
Level 5: Patterns of relationships – simple. Students convey knowledge about relationships among concepts of pollination supported by leaps of thought about how the shapes of flowers and their parts contributes to what animal pollinates them. *(ex. - A trumpet flower needs an animal that can get inside the long skinny petals and reach the pollen)*

Level 6: Patterns of relationships – extended. Students show complex relationships among concepts of pollination emphasizing how the shapes of flowers and their parts contributes to what animal pollinates them AND how the animal's characteristics are helpful for pollination. *(ex - A bird has a long skinny beak that can reach the pollen inside a trumpet flower.)*



Comprehension Post-test

- Participants are pulled in a whole group setting and administered the comprehension assessment
- After the assessment is complete, the researcher will review the design challenge with the students and point out places in the comprehension texts that would have helped with the design. This serves as the explicit instruction on the graphical devices.



GDCA Posttest

- Participants are retested with the GDCA and the results are compared with initial testing.

GDCA Results

Table 24

Comparisons of GDCA Pre/Posttest Scores for Total Participants

GDCA Subsection	M	n	SD	SEM	df	*t*	p	ES
Diagrams								
pretest	86.67	6	11.69	1.71	5	3.08	0.027*	1.26
posttest	97.50	6	4.18	4.77				
Cross-sectional Diagrams								
pretest	77.50	6	5.24	1.67	5	2.08	0.093 [a]	0.85
posttest	81.67	6	4.08	2.14				
Tables								
pretest	63.89	6	12.55	4.12	5	2.50	0.055 [a]	1.02
posttest	77.78	6	10.09	5.12				
Scaled Score								
pretest	76.02	6	6.32	2.58	5	3.46	0.018*	1.41
posttest	85.65	6	1.77	0.72				

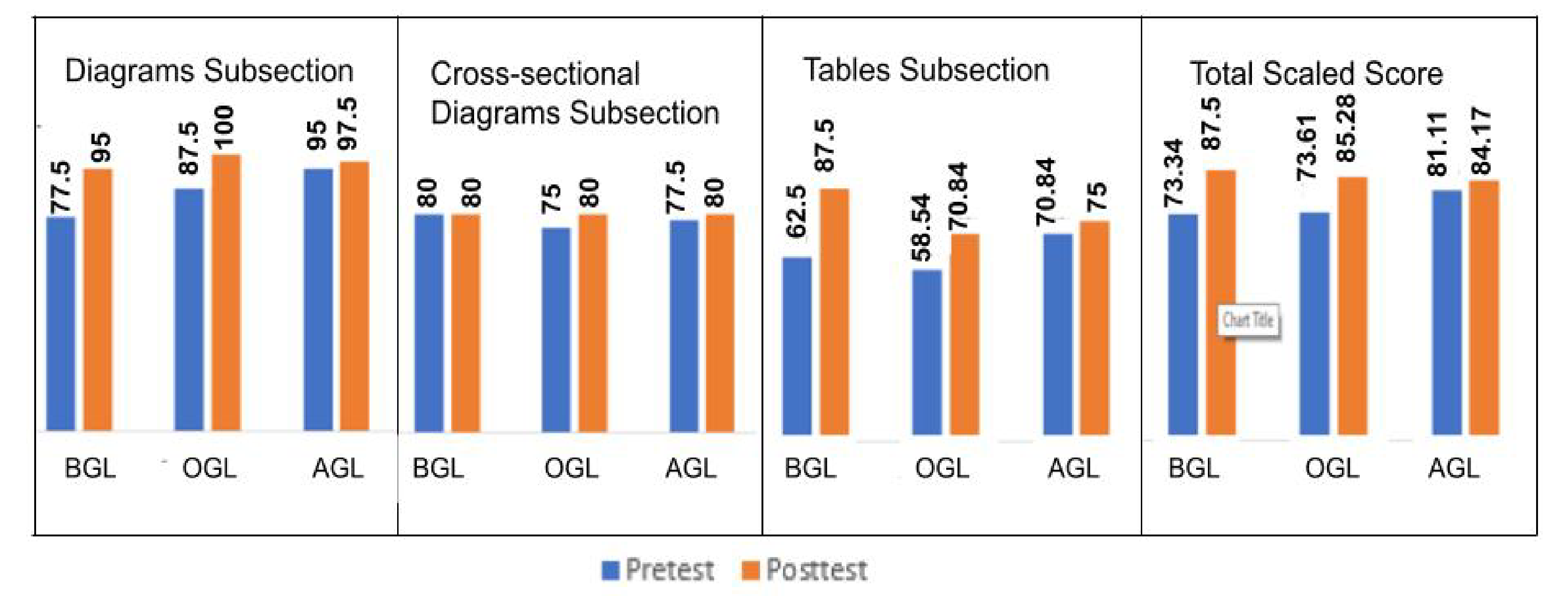
Note. *p <.05, two-tailed, paired, [a] = H_0 cannot be rejected with an α of 0.05

- The results from the total participants' pretest and posttest results for the diagrams subsection of the GDCA indicated a significant difference between the pretest and the posttest $t(5)=3.081$, $p=0.027$. Cohen's *d* ($d=1.26$ CI 95% [0.13-2.33]) exceeded the benchmark for a large effect size ($d=0.80$).

- The participants in this study did not significantly improve their general understanding of cross-sectional diagrams or tables, though the p-value for tables was approaching significance.

GDCA Results

- Overall higher post scores across all dyads, with the greatest seen in the Diagrams and Tables subsections
- BGL and OGL dyads largest pre/post increases in the Diagrams and Tables subsections and Scaled Scores.
- General understanding of diagrams between the BGL and AGL dyads equalizes following engagement in T/E DBL
- AGL dyads demonstrated the least pre/post increase in GDC
- Across all reading levels, the greatest impact on GDC can be seen in the diagrams and tables subsections.



Reading Comprehension Assessment Pre/Post Results

Participant Pre/Post Reading Comprehension Scores by Design Challenge

Participant		Design Challenge 1		Design Challenge 2		Design Challenge 3	
		pre	post	pre	post	pre	post
Participant 1(BGL)							
	Science passage	3	3	1	4	3	4
	Engineering passage	2	2	3	3	3	4
Participant 2 (BGL)							
	Science passage	1	1	1	4	2	2
	Engineering passage	0	1	2	3	1	2
Participant 3 (OGL)							
	Science passage	2	2	2	2	4	4
	Engineering passage	2	1	1	2	2	3
Participant 4 (OGL)							
	Science passage	2	2	1	2	3	3
	Engineering passage	2	2	1	2	2	2
Participant 5 (AGL)							
	Science passage	3	4	2	4	3	3
	Engineering passage	2	2	3	3	3	3
Participant 6 (AGL)							
	Science passage	2	2	2	2	3	3
	Engineering passage	2	2	3	2	3	3

Note. BGL = below grade level; OGL = on-grade level; AGL = Above grade level 0= no PK, 1 = PK of facts - simple, 2 = PK of facts - extended, 3 = PK of concepts - simple, 4 = PK of concepts - extended, 5 = PK of relationships - simple, 6 = PK of relationships - extended

- In Design Challenge 1, only two participants increased comprehension levels from pre to post assessments.
- In Design Challenge 2, eight participants increased comprehension levels from pre to post assessment.
- In Design Challenge 3, only 4 participants increased comprehension levels from pre to post assessments.
- Participants were going though standardized testing during the third design challenge which may have impacted the scores.

Participant Pre/Post Reading Comprehension Scores by Design Challenge

Participant		Design Challenge 1		Design Challenge 2		Design Challenge 3	
		pre	post	pre	post	pre	post
Participant 1(BGL)							
	Science passage	3	3	1	4	3	4
	Engineering passage	2	2	3	3	3	4
Participant 2 (BGL)							
	Science passage	1	1	1	4	2	2
	Engineering passage	0	1	2	3	1	2
Participant 3 (OGL)							
	Science passage	2	2	2	2	4	4
	Engineering passage	2	1	1	2	2	3
Participant 4 (OGL)							
	Science passage	2	2	1	2	3	3
	Engineering passage	2	2	1	2	2	2
Participant 5 (AGL)							
	Science passage	3	4	2	4	3	3
	Engineering passage	2	2	3	5	3	3
Participant 6 (AGL)							
	Science passage	2	2	2	2	3	3
	Engineering passage	2	2	3	2	3	3

Note. BGL = below grade level; OGL = on-grade level; AGL = Above grade level 0= no PK, 1 = PK of facts - simple, 2 = PK of facts - extended, 3 = PK of concepts - simple, 4 = PK of concepts - extended, 5 = PK of relationships - simple, 6 = PK of relationships - extended

- In Design Challenge 1, only two responses used graphical devices in their responses
- In Design Challenge 3, nine responses used graphical devices

Reading Comprehension Assessment Pretest Comparison Results

Table 35

Participant Average Pretest Reading Comprehension Scores

Participant	Design Challenge 1	Design Challenge 2	Design Challenge 3
Participant 1(BGL)	2.50	2.00	3.00
Participant 2 (BGL)	0.50	1.50	1.50
Participant 3 (OGL)	2.00	1.50	3.00
Participant 4 (OGL)	2.00	1.00	2.50
Participant 5 (AGL)	2.50	2.50	3.00
Participant 6 (AGL)	2.00	2.50	3.00

Note. BGL = below grade level; OGL = on-grade level; AGL = Above grade level

- Results of the within subject ANOVA indicate that there was a significant increase in combined pretest scores between design challenges $F(2, 10) = 7.71$, $p = <0.009$, partial $\eta^2 = 0.607$
- Post hoc comparisons show a significant increase in combined pretest scores between design challenge 1 and design challenge 3.

Table 36

Combined Pretest Post Hoc Comparisons Results

Comparison					
Design Challenge		Design Challenge	MD	SE	*p*
Design Challenge 3	-	Design Challenge 1	0.75	0.12	0.003*
	-	Design Challenge 2	0.83	0.25	0.060
Design Challenges 2	-	Design Challenge 1	-0.83	0.30	1.00

Note. MD = Mean difference; SE = standard error, *p<.01

Reading Comprehension Assessment Pretest Comparison Results

Table 34

Science Pretest Post Hoc Comparisons Results

Comparison					
Design Challenge		Design Challenge	MD	SE	*p*
Design Challenge 3	-	Design Challenge 1	0.83	0.31	0.127
	-	Design Challenge 2	1.50	0.25	0.003*
Design Challenges 2	-	Design Challenge 1	-0.67	0.33	0.306

Note. MD = Mean difference; SE = standard error, *p<.01

- Results of the within subject ANOVA indicate that there was not a significant increase in pretest scores between design challenges $F(2, 10) = 1.857$, $p = <0.206$ partial $\eta^2 = 0.271$ for the engineering texts.
- Results of the within subject ANOVA indicate that there was a significant increase in pretest scores between design challenges for the science texts $F(2, 10) = 13.261$, $p = <.002$, partial $\eta^2 = 0.726$.
- Post hoc comparisons indicate a significant increase in science pretest scores between design challenge 2 and 3.

Did Prior Knowledge Impact Pretest Scores?

Table 22

Science/Engineering Prior Knowledge (PK) Scores per Design Challenge

Participant	PK Scores Irrigation (Challenge 1)		PK Scores Packaging (Challenge 2)		PK Scores Pollinator (Challenge 3)	
	S	E	S	E	S	E
Participant 1 (BGL)	0	0	0	1	0	0
Participant 2 (BGL)	2	0	0	1	0	0
Participant 3 (OGL)	2	0	0	2	1	0
Participant 4 (OGL)	2	0	0	1	1	0
Participant 5 (AGL)	2	1	0	1	1	0
Participant 6 (AGL)	2	1	0	2	1	2

Note. S = Science Text; E = Engineering Text, BGL=Below Grade Level, OGL=On Grade Level, AGL = Above Grade Level, 0 = no PK, 1 – PK of facts - simple, 2 = PK of facts - extended, 3 = PK of concepts - simple, 4 = PK of concepts - extended, 5 = PK of relationships - simple, 6 = PK of relationships - extended

- The participants which had higher pretest scores for Design Challenge 1 (participants 1, 2, and 5) did not match with higher prior knowledge scores (participant 1 scored 0, participants 2-6 scored a 2).
- In Design Challenge 3, the participants which had higher pretest scores for Design Challenge 3 (participants 2, 3, and 4) did not match with higher prior knowledge scores (participants 1 & 2 scored 0, participants 3-6 scored 1).

Table 40

Participant Total Text Interactions

Participant	Frequency of interactions with the text		
	Design Challenge 1	Design Challenge 2	Design Challenge 3
P 1 BGL	2	1	35
P 2 BGL	3	3	28
P 3 OGL	1	0	22
P 4 OGL	0	1	18
P 5 AGL	13	10	30
P6 AGL	9	11	31

Note. P = participant; BGL = below grade level; OGL – on-grade level; AGL = Above grade level

Table 41

Frequency of Text Interactions Post Hoc Comparisons Results

Comparison					
Design Challenge		Design Challenge	MD	SE	*p*
Design Challenge 1	-	Design Challenge 2	0.333	.715	1.000
	-	Design Challenge 3	22.667	2.376	.000642*
Design Challenges 2	-	Design Challenge 3	23.000	2.449	.000693*

Note. MD = Mean difference; SE = standard error, *p<.01

- Results of the within subject ANOVA indicate that there was a significant difference in frequency counts between design challenges $F(2, 10) = 85.795$, $p = <.001$, partial $\eta^2 = 0.945$.
- Post Hoc comparisons indicated a statistically significant increase from design challenge 1 to 3 and from design challenge 2 to 3

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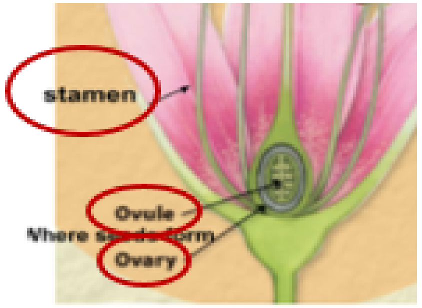
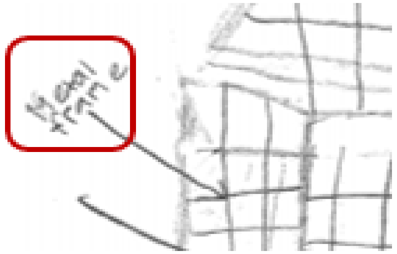
<tr><th>Graphical Device</th><th>Participant Response</th></tr>
<tr><td>Challenge: Flowers and Pollination

</td><td>Category: Exact Quote
</td></tr>
<tr><td>Challenge: Designing a Greenhouse
Greenhouse Building Materials<table>
<tr><th>Part of greenhouse</th><th>Material it is made out of</th><th>Part's job</th></tr>
<tr><td>Covering</td><td>Clear plastic or glass</td><td>to let sunlight through</td></tr>
<tr><td>Frame</td><td>Metal, wood, hard plastic</td><td>to hold up the covering and withstand wind</td></tr>
<tr><td>Floor</td><td>Soil, wood, brick, stone, plastic</td><td>to hold on to heat from the sun and protect from the cold of the ground</td></tr>
</table></td><td>Category: Excerpt
</td></tr>
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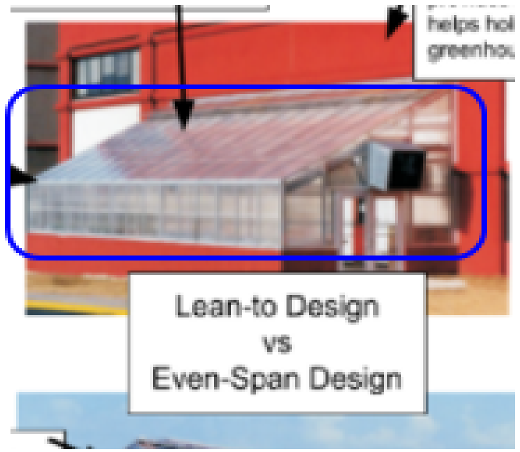
</td><td>Category: Image
</td></tr>
</table>

- Science and engineering passages were analyzed for words and phrases only used in the graphical devices and were identified as "unique"
- Participant responses were then analyzed for instances where the unique words and phrases were used
- These data were categorized into three usage types: an exact quote of a unique graphical device word or phrase, an excerpt of the unique word or phrase, an image, or part of image, from the graphical device.

Table 42

Unique Words/Phrases from Graphical Devices Used in Participant Design Challenge Responses

	Design Challenge 1		Design Challenge 2		Design Challenge 3	
	Unique words/phrases	Participant usage	Unique words/phrases	Participant usage	Unique words/phrases	Participant usage
P1 & 2 (BGL)	n/a	none	n/a	none	Stamen (D)	"stamen" labels picture of a flower
					Ovule (D)	"ovule" labels picture of a flower
					Petals (D)	"petals" labels picture of a flower
					Shape of flower diagram (D)	Shape of flower used in sketch matches that used in the science passage.
P3 & 4 (OGL)	n/a	none	Soil, wood, brick, stone (T)	"soil" labeled as bottom of plant box	Stamen (D)	"stamen" labels picture of a flower
					Petals (D)	"petals" labels picture of a flower
					Shape of flower diagram (D)	Shape of flower used in sketch matches that used in the science passage.
P5 & 6 (AGL)	n/a	none	Soil, wood, brick, stone (T) Floor (T)	"wood floor"	Stamen (D)	"stamen" labels picture of a flower
			Metal, wood, hard plastic (T) Frame (T)	"metal frame"	Ovule (D)	"ovule" labels picture of a flower
			Image of lean-to greenhouse (D)	Image used when drawing a greenhouse in sketch	Petals (D)	"petals" labels picture of a flower
					Small fuzzy hairs covering body/leg (D)	"Hair like bee to get pollen stuck"

Note. D = found in diagram, T = found in Table, P = participant, BGL = below grade level, OGL = on grade level, AGL = above grade level

- Unique words and phrases used in design challenge responses increased from none in the first design challenge to 11 in design challenge 3.
- Of all the unique words and phrases used, 12 out of the 15 were diagrams

Research Conclusions and Implications

- T/E DBL Challenges address common issues with GDC
  - will increase student text interactions
  - Equalizes below grade level readers in GDC of diagrams and tables with above grade level readers
- T/E DBL is effective to statistically significant levels as a method for improving comprehension of unfamiliar science texts
  - T/E DBL supports an increase in comprehension of engineering texts, but further research is necessary to determine if there is a statistically significant impact
- T/E DBL challenges support a deeper level of understanding of graphical devices in unfamiliar texts
  - More higher level responses given on comprehension pretests
- Pedagogical
  - Reading, specifically of graphical devices, should be considered a science and engineering practice that is part of the design process
  - T/E DBL should be considered alongside the other reading pedagogical approaches.

Significance of T/E DBL for GDC

#1 Graphical device comprehension and general reading comprehension (nonfictional/informational text)

- Few formal TEE programs at the elementary level – most are STEM/STEAM programs
- ELED programs largely implemented from a science perspective
- Educators well-versed in I-STEM ED pedagogy can implement T/E DBL as an authentic designerly way of learning
- This research demonstrates the power of DBL for teaching content and practices difficult to teach in other disciplines

#2 Findings: across all participants, engagement in T/E DBL resulted in

- Increased text interactions and usage of graphical devices
- Promoted general GDC for diagrams and tables
- Improved comprehension of unfamiliar science texts
- Greater benefits for below grade level readers

#3 Significance: Technology/Engineering Design Based Learning as a viable pedagogy for:

- Improving situational (contextual) interpretation of graphical devices within discipline-specific texts
- Enhancing constructed understandings of embedded disciplinary concepts
- Recognition of additional information contained within graphical devices
- Transfer and application of graphical device knowledge in novel situations in other disciplines

Technological and Engineering Design Based Learning: Promoting Upper Elementary Graphical Device Comprehension

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