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

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ABSTRACT

The research presented is an investigation into the use of technological and engineering design based learning (T/E DBL) as an instructional strategy to facilitate student comprehension of nonfiction/informational text inclusive of graphical devices. The research design followed a mixed method exploratory embedded case study. Six 5th grade participants were examined as both a whole group and as reading level dyads (below, on, and above grade level) as they progressed through three T/E DBL challenges designed to intentionally support graphical device comprehension (GDC) instruction. Data were collected from a variety of instruments used to assess participant prior knowledge, comprehension of graphical devices, and resultant reading comprehension of both familiar and unfamiliar texts. Analysis of data generated detailed descriptions of the reading comprehension levels for each participant throughout the study. Findings indicate that T/E DBL increased text interactions and graphical device usage across all participants, promoted their development of general GDC for diagrams and tables, improved their comprehension of unfamiliar science texts, and proved to be of particular benefit to below grade level readers. These results demonstrate the viability of T/E DBL as a valuable component of elementary level reading instruction for improving student use and comprehension of graphical devices, and for improving their overall comprehension of unfamiliar science and engineering texts where embedded graphical devices present new content in a visual information genre.

Key Words: Design Based Learning, Graphical Device Comprehension, Reading Instruction, Science Comprehension, Engineering Comprehension

1. MOTIVATION

Throughout the past two decades, the role of nonfiction/informational text within K–12 literacy instruction within the United States has undergone significant changes in an attempt to meet the current national educational needs (National Governors Association & Council of Chief State School Officers, 2020). As needs, practices, and goals within education change, the National Assessment of Educational Progress (NAEP) adjusts its development of assessment guidelines to establish national baseline assessment expectations (NAEP, 2019). Although the NAEP emphasis on nonfiction texts has significantly increased over the past decade, recent national test scores indicate that comprehension of nonfiction/informational text continues to be a particular weakness. In spite of this increased emphasis, the current weak performance of U.S. students on standardized nonfiction/informational reading assessments raises serious questions about best practices for nonfiction/informational text comprehension instruction.

Reading instruction within disciplines and/or using discipline-specific texts calls for disciplinary-specific literacy instruction. Disciplinary literacy acknowledges the discipline as a whole, and recognizes that form (genre) will follow function (the discipline) – "one learns how to read or write a genre through experience with that genre" (Duke, 2000, p. 206). Specifically, the situational (contextual) interpretation of discipline-specific text is critical to constructing an understanding of the concepts within that text. As such, educators in a specific discipline must design contextual experiences that require students to "engage, elicit/engineer, examine, and evaluate" the language within the discipline in order to develop disciplinary literacy (Moje, 2015, p. 260). The complex structures of discipline-specific informational/nonfiction text are not the only impediments to nonfiction text comprehension.

One such barrier is limited student interactions with informational texts in the classroom (Duke, 2000). Even more problematic is the inclusion of graphical devices. Graphical devices are images (structures) within texts that serve as a means for introducing new information and/or concepts through a visual structure such as: diagrams, flow diagrams, graphs, timelines, maps, tables, images, and simple photographs. However, due to their visual nature, graphical devices are not processed and understood by students in the same way as other nonfiction text features (Poivio, 1971; Sadowski & Paivio, 2001; Roberts et al., 2015).

Graphical devices are an integral part of both science and engineering disciplines and their disciplinary texts. Despite the intrinsic role graphical devices play in engineering, currently no research exists on how authentic engineering activities may support graphical device comprehension (GDC). This constitutes a significant gap in the research on discipline-specific reading comprehension instruction demonstrated to better prepare students to evaluate the unique languages within a given discipline.

One promising and overlooked avenue for enhancing GDC specific to engineering at the K-12 level is the use of authentic technological and engineering design-based learning (T/E DBL) experiences. T/E DBL is a pedagogical approach that intentionally teaches the content and practices of STEM disciplines. Immersing learners in T/E DBL imposes on them the need for higher-order thinking while engaged in designing T/E solutions where they "design to understand" (Wells, 2016a, p. 15). Within this context, the research presented in this paper examined the use of T/E DBL challenges as a strategy for facilitating student comprehension of nonfiction/informational text wherein the inclusion of graphical devices provides essential disciplinary information.

2. THEORETICAL FRAMEWORK

2.1. Graphical Device Comprehension (GDC)

Reading comprehension research encompasses a diverse set of theoretical, empirical, and pedagogical approaches that require a clear and comprehensive definition of reading comprehension. For the purposes of this study, reading comprehension is defined as “an active process that involves using knowledge of written text, language, and the greater world to create meaning through mental representations of the text” (Morgan, 2022). This definition combines that of the Rand Reading Study Group which states that reading comprehension is “the process of simultaneously extracting and constructing meaning through interaction and involvement with written language” (Snow, 2002, p. 11) with the emphasis on prior knowledge and situational interpretation of the text in Kintsch’s Construction-Integration model. It is important to acknowledge that the term “written text” in this study’s definition includes both continuous text and graphical devices.

Graphical devices are images whose inclusion in texts contributes to the overall purpose of the text by contributing information unique from the continuous text (Fingeret, 2012). Roberts et al (2015) proposed that the distinct process of understanding the purpose of a graphical device, understanding how to use different graphical devices to extract information, and the ability to explain the information within the graphical device can be called graphical device comprehension (GDC). As such, GDC will significantly contribute to a reader’s overall comprehension of a text that includes both continuous text and graphical devices. A complete understanding of GDC and the role it plays in reading comprehension begins with understanding the theoretical underpinnings of how literacy of visual elements differs from the comprehension of written text.

2.2. GDC and Elementary Nonfiction Text Comprehension

Paivio’s Dual Coding Theory, the Cognitive Theory of Multimedia Learning, and The Integrated Model of Text and Picture Comprehension all propose that verbal (language-based) information is processed differently from visual information and how mental models are formed (Paivio, 1971; Sadowski & Paivio, 2001; Mayer, 2005; Schnotz, 2005). Therefore, given GDC and comprehension of continuous text are achieved through different processes, the distinctions between the two types of comprehension must be considered when examining instructional methods of reading teachers. Specifically, GDC must be considered within the greater context of how it contributes to overall reading comprehension of nonfiction texts as a whole. This is particularly significant given the unique information contained in graphical devices and the requisite understanding of the graphical device in order for the reader to fully grasp nonfiction text (Fingeret, 2012; Guo et al, 2018).

A close examination of the research literature indicates there are multiple potential issues regarding comprehension of graphical devices embedded in nonfiction reading comprehension. Readers often fail to acknowledge graphical devices (Hannus & Hyona, 1999). Readers may not attempt to comprehend the information in the graphical device and instead spend that time “not thinking about anything” (Norman & Roberts, 2015, p 49). In addition, GDC requires understanding the structures of graphical devices themselves and the integration of information drawn from the graphical devices with that found in the continuous text (Roberts & Bruger, 2017; Guo et al, 2018). Certain instructional practices potentially negatively impact GDC. For example, teachers may choose to simply identify the presence of graphical devices in text or may decrease their level of explanation as the devices grow in complexity (Coleman et al., 2011). Teachers may base their instructional decisions on the erroneous inculcation method, in which learning to decode words within a non-fiction text is believed to provide sufficient skills to understand the more complex structures within that text (Madden et al., 2014).

2.3. T/E DBL: Context for GDC

The 2019 NAEP Reading Framework states “the situation for reading often determines the way that readers prepare for and approach their task” (National Center for Education Statistics, US Department of Education, 2019, p. 3), demonstrating the importance of authentic contexts in reading comprehension. However, there remains a paucity of research addressing GDC pedagogies where readers are specifically encouraged to explore the content in context as a strategy for promoting their comprehension of nonfiction text (Schugar & Dreher, 2017). Those few prior studies investigating reading comprehension supported through authentic tasks and practices only addressed authentic science tasks (Romance & Vitale, 2005; Guthrie et al., 2006). More importantly, all were focused on nonfiction reading comprehension as a whole, not on GDC specifically.

Promoting GDC within authentic contexts necessitates an understanding of how graphical devices are used in those disciplines where they are an integral component of disciplinary practices. One such discipline is engineering whose practices are “best communicated through sketches, diagrams, graphs, models, and products” (National Research Council, 2012, p.74). Emphasis on both GDC and engineering through the design of technological solutions increases at the upper elementary level, presenting engineering as an authentic context for GDC where T/E DBL is employed as the pedagogical approach. T/E DBL utilizes open-ended design challenges to intentionally impose a genuine need to explore concepts inherent to the design of a viable solution and immerses them in the content and practices of the engineering disciplines (Hmelo et al., 2000; Wells, 2016b; Wells, 2021; Wells & Van de Velde, 2020) where understanding and using graphical devices is an inherently required skill. As such, T/E DBL provides the opportunity for teaching GDC within a truly authentic context. To address the gap in the research on this method, this study examined the relationships between GDC and student engagement in T/E DBL engineering challenges as an integral part of fifth grade reading instruction. The research question guiding this study asked: What relationship exists between design-based learning challenges which are supported by discipline-specific graphical devices and students’ (a) frequency of use of discipline-specific graphical devices, (b) comprehension of science and engineering discipline-specific graphical devices in texts which are used to support the design-based learning challenge, and (c) comprehension of science and engineering discipline-specific graphical devices in novel texts?

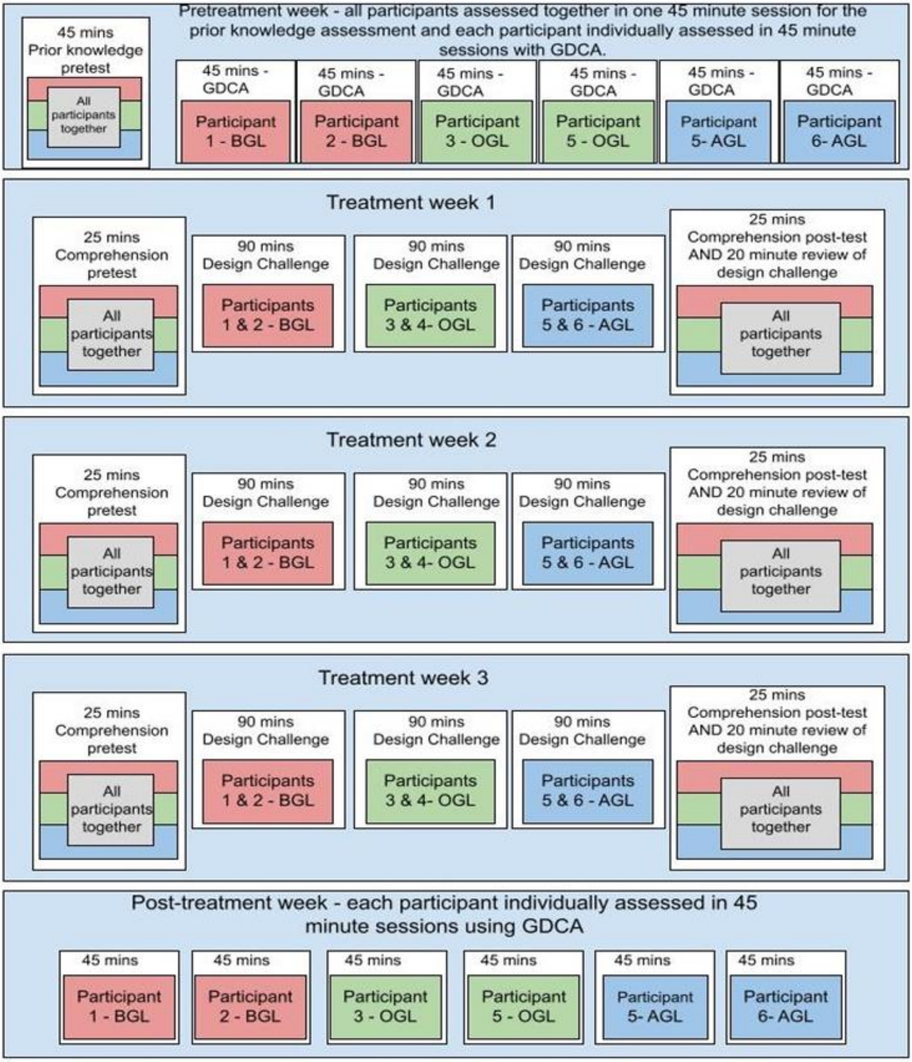
3. METHOD

The research design employed for this study followed a mixed method exploratory embedded, multiple case study approach, wherein qualitative data collected from a variety of instruments were used to assess a participant's prior knowledge, general GDC levels, and resultant reading comprehension of both familiar and unfamiliar texts. Participants were a stratified purposeful sampling of fifth grade students examined as both whole group and reading level dyads (below grade level [BGL], on grade level [OGL], above grade level [AGL]) during their progression through three T/E DBL challenges. Each design challenge was specifically developed to support instruction of elementary students in their use of graphical devices, and lead to improved overall reading comprehension.

3.1. T/E DBL Implementation

This study was conducted over a period of five weeks, consisting of a 1-week pretreatment period, three 1-week treatment cycles, and a 1-week post-treatment period (Fig. 1).

Figure 1.
Research Implementation Schedule



3.2. Measures

3.2.1. Graphical Device Comprehension Assessment (GDCA)

The Graphical Device Comprehension Assessment (GDCA) is an instrument created by Roberts, Norman, and Cocco (2015) to assess GDC. The GDCA generates a profile of a reader's comprehension of seven common graphical devices. During GDCA administration participants are asked to name and explain the graphical devices to create a scaled score for each graphical device that are averaged to determine an average scaled score. The GDCA was used in this study as a means of documenting GDC changes as a result of engagement in T/E DBL. Only questions on tables, surface, and cross-sectional diagrams were selected and modified from the original GDCA to specifically target graphical device categories prevalent in authentic science and engineering content and practices.

3.2.2. Reading Comprehension Assessment

The reading comprehension assessment rubric used in this study is a modified version of the one developed by Taboada et al. in 2009. Reading comprehension was assessed by having participants read content-specific passages and then generate written responses to an open-ended prompt. Responses are evaluated and given a score of 1 to 6 based on a six-level scoring rubric. Three science-focused passages and three engineering-focused passages were developed to target specific science and engineering concepts (Table 2) inherent to the design challenges that aligned with standards listed in the Standards for Technological and Engineering (ITEEA, 2000, 2020) and in Virginia's Science Standards of Learning.

Table 2.
Alignment of Standards-Based Concepts for Reading Comprehension Assessment Passages

Passage Topic	Concepts Targeted in Applicable Standard
Technological Systems	STEL-2M Differentiate between inputs, processes, outputs, and feedbacks in technological systems (ITEEA, 2020)
Greenhouse Design	STEL-2I Describe the properties of different materials (ITEEA, 2020)
Biomimicry	STEL 2J Demonstrate how tools and machines extend human capabilities, such as holding, lifting, carrying, fastening, separating, and computing (ITEEA, 2020)
Types of Roots	4.2 The student will investigate and understand that plants and animals have structures that distinguish them from one another and play vital roles in their ability to survive. Key ideas include b) plants and animals have different structures and processes for obtaining energy (VA DOE, 2018a)
Greenhouse Effect	5.6 The student will investigate and understand that visible light has certain characteristics and behaves in predictable ways. Key ideas include a) visible light is radiant energy that moves in transverse waves; b) the visible spectrum includes light with different wavelengths; c) matter influences the path of light; and d) radiant energy can be transformed into thermal, mechanical, and electrical energy (VA DOE, 2018b)
Flowers & Pollination	4.2 The student will investigate and understand that plants and animals have structures that distinguish them from one another and play vital roles in their ability to survive. Key ideas include c) plants and animals have different structures and processes for creating offspring (VA DOE, 2018a)

Passages about the targeted science and engineering concepts that included graphical devices were drawn from grade-level appropriate trade books, textbooks, instructional passages, and informational websites. Passages were used with only slight modifications made when necessary to maintain alignment with the research design. Six separate six-level rubrics were developed using similar language and classification requirements to those in the 2009 Taboada et al. study rubrics to maintain item validity. As the rubric score increased in level, the complexity of use of graphical devices also increased.

3.2.3. Design Challenges

Provided as the T/E DBL context for the study, participants participated in a series of three Design No Make (DNM) challenges, each created with graphical devices embedded in the reading passages containing information critical to designing a solution. The three DNM challenges addressed the topics of irrigation, plant packaging, and pollination respectively, and contained detailed criteria written intentionally to necessitate the use of the embedded graphical devices. As a DNM, participants were asked to sketch and explain a design without building a prototype. Post-design challenge questions were included to guide participants towards use of the reading passages and to provide a uniform approach for post-design challenge discussions. All design challenge sessions were audio/video recorded for later analysis.

3.2.4. Frequency Observation Instrument

The Frequency Observation Instrument (Fig. 2) was a rubric developed to monitor the frequency of participant references to graphical devices embedded in passages read during a design challenge. The design criteria in each T/E DBL challenge were written to deliberately require information found only in a graphical device. As a result, all participant references to passages read during the T/E DBL challenge were specifically to an embedded graphical device.

Figure 2.
Frequency Observation Rubric

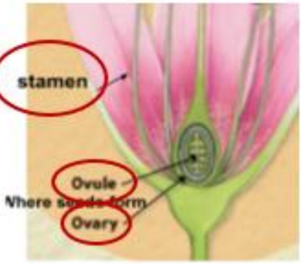
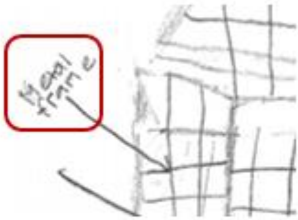
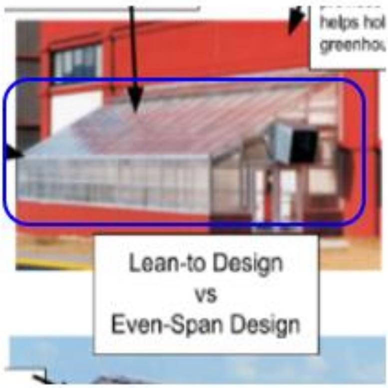
Observation Period	Behaviour Descriptors	Tallies	Time Stamps
Initial Design Phase			
	student looks at passages with no oral discussion (including self-talk) or dyad interaction		
	student initiates interaction with passages by referencing information orally (including self-talk) while looking at passages		
	student initiates interaction with passages by pointing to passages with or without oral communication		
	student interacts with passages in response to partner's verbal or nonverbal reference to the passages		
	student interacts with passages in response to researcher's questioning or prompts		
Iteration Phase			
	student looks at passages with no oral discussion or dyad interaction		
	student initiates interaction with passages by referencing information orally while looking at passages		
	student initiates interaction with passages by pointing to passages with or without oral communication		
	student interacts with passages in response to partner's verbal or nonverbal reference to the passages		
	student interacts with passages in response to researcher's questioning or prompts		

The rubric for recording observation frequencies also denoted the type of text interaction and if the interaction occurred during the initial design or iteration phase.

3.2.6 Content Analysis of Participant Design Challenge Responses

The frequency of passage interaction indicates how often the interaction occurs but does not specify what graphical device information is actually being used by the participant. Content analysis of participant responses was conducted to indicate the type(s) of interaction specific to the graphical device. Any words or phrases used in the graphical devices embedded in the design challenge reading passages that were not used anywhere in the continuous text of the passages were identified as “unique”. Participant responses (Fig. 3) were then analysed for instances where these unique words and phrases were used.

Figure 3.
Examples: Student Responses Demonstrating Categories of Graphical Device Usage

<table>
<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
<table>
<tr><th colspan="3">Greenhouse Building Materials</th></tr>
<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>
<tr><td>Challenge: Designing a Greenhouse

</td><td>Category: Image
</td></tr>
</table>

4. RESULTS

Pre and Post intervention administration of the GDCA instrument provided data comparisons (Table 3) regarding the participants' comprehension of the purposes of graphical devices as well as their comprehension of the information contained within those devices.

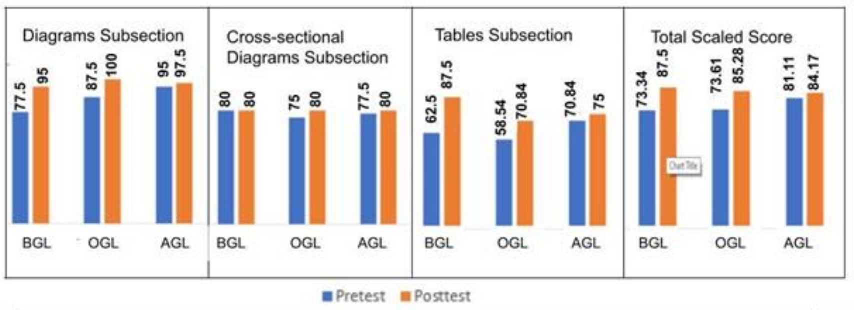
Table 3.
Comparison of Pre/Post-test GDCA Scores for Total Participants

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

To determine statistically significant differences between pre and post-tests, mean scores of the total population for each subsection of the GDCA were analysed using a paired *t*-test with an alpha of 0.05. Similarly, mean scaled scores were analysed for statistical significance of the GDCA as a whole. Analyses indicate significance for the Diagrams subsection and for the Scaled Scores. It is of note that the Tables Subsection was approaching significance. Given the low number of participants in each reading level, the comparison of dyad pre/post GDCA data was conducted (Fig. 4) to simply identify any patterns and/or information not accurately reflected in the statistical analyses.

Figure 4.
Subsection Score Pre/Post Comparisons by Reading Level Dyad



Note. BGL – below grade level; OGL – on grade level; AGL = above grade level

Analyses reveal overall higher post scores across all dyads, with the greatest impact on GDC seen in the Diagrams and Tables subsections, as well as in the Scaled Scores for the BGL and OGL dyads. Interestingly, while the Diagrams pre-test scores for the BGL and AGL dyads had the largest difference (17.5), the post-test difference between these two dyads was only 2. These findings indicate that the general understanding of diagrams between the BGL and AGL dyads equalizes following engagement in T/E DBL. Furthermore, findings demonstrate the greatest impact of T/E DBL engagement is increased understanding of diagrams and tables.

4.1. Reading Comprehension

Reading comprehension was assessed before and after each T/E DBL challenge. As described previously, participants received a score from zero to six that represented their level of comprehension of the text, with scores above 2 denoting the use of graphical devices in the responses. For Design Challenge 1, data in Table 4 show only participants 1 and 5 receiving pre-test scores of 3 reflecting minimal use of graphical devices in their responses, while in Design Challenge 3 only three post-tests' scores indicate graphical devices were not used. These findings demonstrated that by the end of the study for both science and engineering passages, more participants used graphical devices in their responses. In addition, twenty-four out of thirty-six (75%) of the reported scores increased from the pre-test to the post-test.

Table 4.
Participant Pre/Post Reading Comprehension Score per Design Challenge

Participant	Passage	Design Challenge 1		Design Challenge 2		Design Challenge 3	
		pre	post	pre	post	pre	post
P1: BGL							
	Science	3	3	1	4	3	4
	Engineering	2	2	3	3	3	4
P2: BGL							
	Science	1	1	1	4	2	2
	Engineering	0	1	2	3	1	2
P3: OGL							
	Science	2	2	2	2	4	4
	Engineering	2	1	1	2	2	3
P4: OGL							
	Science	2	2	1	2	3	3
	Engineering	2	2	1	2	2	2
P5: AGL							
	Science	3	4	2	4	3	3
	Engineering	2	2	3	5	3	3
P6: AGL							
	Science	2	2	2	2	3	3
	Engineering	2	2	3	2	3	3

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

4.2. Pre-test Comparisons

Since the Reading Comprehension Assessment pre-tests were unfamiliar to the participants, the pre-test scores can be used to determine how participants comprehend novel (unfamiliar) texts. Participants' comprehension of novel science and engineering texts which include graphical devices was evaluated by comparing participants' comprehension assessment pre-test scores across the three design challenges. The pre-test scores for the engineering passages were analysed for statistical significance using a one-way repeated ANOVA with the design challenge (Design Challenge 1, Design Challenge 2, Design Challenge 3) as the independent variable and pre-test scores as the dependent variable. The same method was used for the pre-test scores for the science passages. Within subject ANOVA results indicate no significant increase in pre-test scores between design challenges $F(2, 10) = 1.86$, $p = <0.206$ partial $\eta^2 = 0.27$ for the engineering texts, demonstrating that participants did not significantly improve their comprehension of novel engineering texts from the beginning of the first design challenge to the third. A second one-way repeated ANOVA was run with the design challenge (Design Challenge 1, Design Challenge 2, Design Challenge 3) as the independent variable and the science reading comprehension pre-test scores as the dependent variable. Within subject ANOVA results indicate a significant increase in pre-test scores between design challenges $F(2, 10) = 13.26$, $p =<0.002$, partial $\eta^2 = 0.73$ and demonstrating that participants' comprehension of novel science texts did increase significantly from the beginning of the first design challenge to the third. The post hoc test results shown in Table 5 revealed that participants' science reading comprehension pre-test scores did significantly increase from Design Challenge 2 (M= 1.50) and Design Challenge 3 (M= 3.00), demonstrating that participants' comprehension of novel science texts significantly increased between those two design challenges.

Table 5.
Comparisons: Science Pretest Post Hoc (n=6)

Design Challenge	M	Design Challenge	M	MD	SE	*p*
Challenge 3	3.00	Challenge 1	1.67	0.83	0.31	0.127
Challenge 3	3.00	Challenge 2	1.50	1.50	0.25	0.003*
Challenge 2	1.50	Challenge 1	1.67	-0.67	0.33	0.306

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

4.3. Frequency Observation Rubric

The Frequency Observation Rubric tracked all interactions of participants with the provided science and engineering texts during the design challenges. Results presented in Table 6 show participant interactions with the passages not only equalized across reading levels, but increased from Design Challenge 1 to Design Challenge 3 for all participants.

Table 6.
Participant Total Text Interactions

Participant	Frequency of text interactions		
	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
P 6 AGL	9	11	31

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

To determine if this increase was statistically significant, a one way repeated ANOVA was run with the design challenge as the independent variables and the total frequency counts as the dependent variable. Results of the within subject ANOVA indicate that there was a significant difference in frequency counts between design challenges $F(2, 10) = 85.80$, $p =< 0.001$, partial $\eta^2 = 0.95$. Participants interacted with the passages significantly more by the last design challenge. Post hoc test results (Table 7) revealed the frequency of text interactions significantly increased from Design Challenge 1 (M= 4.67) to Design Challenge 3 (M= 27.33) and also significantly increased between Design Challenge 2 (M = 4.33) and Design Challenge 3.

Table 7.
Frequency of Text Interaction: Post Hoc Comparisons

Design Challenge	M	Design Challenge	M	MD	SE	p
Design Challenge 1	4.67	Design Challenge 2	4.33	0.33	.72	1.000
Design Challenge 1	4.67	Design Challenge 3	27.33	22.67	2.38	.000642*
Design Challenges 2	4.33	Design Challenge 3	27.33	23.00	2.45	.000693*

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

4.4. Content analysis

Content analysis of student responses to the design challenges was used to identify unique words or phrases that had been drawn from either the diagram or table within the texts (Table 8).

Table 8.
Instances of Information Drawn from Graphical Devices

Reading Level	Design Challenge 1 GD Information		Design Challenge 2 GD Information		Design Challenge 3 GD Information	
	Tables	Diagrams	Tables	Diagrams	Tables	Diagrams
BGL	0	0	0	0	0	4
OGL	0	0	1	0	0	3
AGL	0	0	2	1	0	4

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

Results indicate the use of unique words and phrases taken from graphical devices increased across design challenges and an increased use not only by the above-grade dyad, but by dyads at all levels. This increased use of content from graphical devices by all participants demonstrates they interacted with the graphical devices more frequently as the study progressed.

5. CONCLUSIONS

The impetus for this research was the continued weak performance of U.S. elementary students on national assessments of reading comprehension. Such weak performances suggest a need for disciplinary-specific literacy instructional strategies that more effectively promotes student reading comprehension in general. More importantly, strategies that promote comprehension of nonfiction/informational text inclusive of graphical devices containing essential disciplinary information.

Results from this case study clearly demonstrate the potential of T/E DBL for developing design thinking in learners at the elementary level which transfers to other disciplines. The pedagogical approach used in T/E DBL provides elementary educators with instructional strategies that uniquely prepare young learners to recognize, comprehend, and use disciplinary information contained within graphical devices. Learners prepared to utilize a designerly way of coming to know possess the capacity to transfer that knowledge acquisition heuristic (Wells, 2021, p. 235) for interpreting information presented in discipline-specific text inclusive of graphical devices, and which leads to their better understanding of the concepts within that text.

Prior research has recognized that GDC instruction is impacted by the erroneous assumption that teaching students to read continuous text will prepare them to read and understand graphical devices. The unique challenges of GDC will require pedagogical approaches that address those challenges. T/E DBL curricula provide a specific, immediate need and payoff for students using and understanding graphical devices. Findings from this research imply that readers, particularly those who read below grade level, will benefit from GDC instruction through T/E DBL design challenges because they are consistently reinforced in the benefit of using graphical devices by improved designs. Based on findings from this research, one major implication is that elementary reading instruction must acknowledge GDC as a separate process from reading comprehension of nonfiction continuous text and must shift their pedagogy accordingly. Furthermore, this study demonstrates that T/E DBL is a viable pedagogical approach for teaching GDC at the elementary level.

Additionally, providing training to elementary educators on GDC and the role GDC plays in authentic contexts such as science and engineering may be necessary to support the creation and implementation of T/E DBL curricula that effectively support GDC. Just as reading comprehension of continuous text does not automatically transfer to GDC, training focused on teaching decoding and comprehension of continuous text may not automatically transfer to teaching GDC. Teacher preparation and professional development programs must address this need moving forward.

Given this research presents results from a small case study, needed is a larger study employing T/E DBL as an instructional strategy used to promote GDC in elementary level learners. As well, further research is needed investigating those unique technological/engineering design-based learning teaching strategies shown to prepare students with the capacity for design thinking necessary for exploring, comprehending, and understanding information encountered in authentic contexts. Such research will help establish T/E DBL as an integral teaching strategy at the elementary level for better preparing learners as both problem solvers and critical thinkers.

6. REFERENCES

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