Knowledge Abstraction in Technological/Engineering Design Activities

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1. INTRODUCTION

Science, technology, engineering, and mathematics (STEM) literacy is a critical component of 21st century education (AAAS, 1989, 1993; NCTM, 2000; ITEA, 2000). The need for a STEM literate population provides the basis for America's current educational reform agenda. The central tenet of STEM education literacy is the preparation of individuals who are knowledgeable of the connections between the content and practices of the STEM fields. This is in contrast to the silo method of education, which teaches the STEM disciplines independently of each other. When conceived as an integrative curriculum model designed around teamwork and problem-solving environments, Integrative STEM education is an ideal pathway for achieving STEM education literacy (Wells, 2010, 2008).

Each STEM discipline views teaching and learning from a different pedagogical lens. Mathematics educators use problem solving as a way of thinking that involves building and applying abstract, logically connected networks of ideas (Rutherford & Ahlgren, 1990). These networks of abstraction act as a framework for solving novel mathematical problems. Science education employs the scientific method of inquiry. The inquiry activity is generated from student experiences and "predominantly [based] on real phenomena, in classrooms, outdoors, or in laboratory settings, where students are given investigations or guided toward fashioning investigations that are demanding but within their capabilities" (NRC, 1996, p. 31).

Technology education uses an open-ended technological design-based learning (DBL) pedagogy (ITEA, 2000). In open-ended technological design-based learning students are presented with a real world design problem. Students are encouraged to develop their own knowledge base and criteria for their final solution, usually under the guidance of the teacher (Barrows, 1986). The students solve this real world problem using a technological design approach. This approach includes defining the problem, stating a need, collecting information, developing alternative solutions, choosing an optimal solution, prototyping, and evaluation (Hutchinson & Karsnitz, 1994; Raizen, Sellwood, Todd, & Vickers, 1995; Wells, 2008). As the remaining discipline of STEM education, engineering education incorporates science, technology, and mathematics as no other discipline does (EAC, 2004; NAE, 2004). Engineering is essentially a marriage of science, technology, and mathematics applied to help solve real world problems. Engineering education utilizes the engineering design process as a method to solve these real world problems (EAC, 2004; NAE, 2004). Similar to technological design, engineering design is "the systematic and creative application of science and mathematical principles to practical ends such as the design, manufacture, and operation of efficient and economical structures, machines, processes, and systems" (ITEA, 2000, p.238).

The pedagogies of technology education and engineering education utilize a design process to bring science, technology, engineering, and mathematics together in concert to solve real-world problems. This technological/engineering (T/E) design process has strong potential for application in bringing STEM concepts together to solve real-world problems (Wells, 2013, 2010, 2008, 2007a, 2007b, 2006; Dunham, Wells, White, 2002). Throughout the T/E DBL process, there are many opportunities for students to use the knowledge learned in one discipline and apply it to the problems presented in another. For example, if a student is trying to design a bridge he/she needs to have some understanding of forces, which is knowledge learned in physics. The student would also need to understand how to apply mathematical calculations to help solve this problem. This process of activating knowledge gained in one context and used in another is "knowledge transfer." A traditional definition of knowledge transfer is "the ability to apply knowledge or use knowledge from one problem, situation or context to another" (Anderson, 2005). Although Anderson's definition is a broad understanding of knowledge transfer, other researchers have taken a more specific approach to its study. Many theoretical approaches to explaining knowledge transfer are rooted in a belief that knowledge becomes generalizable through its abstraction. Reed, Ernst, and Banerji (1974) and Gick and Holyoak (1980, 1983) hypothesized that the construction of abstract rules, schemata, or other mental representations serve as the primary cognitive support for knowledge transfer. Other theorists in the field also support the belief that abstractions are mental representations of knowledge transfer (Fuchs, Fuchs, Prentice, Burch, Hamlett, Owen, Hosp, & Jancek 2003; Gentner, Loewenstein, & Thompson, 2003; Gentner & Markman, 1997; Gentner & Medina, 1998; Reed, 1993; Singley & Anderson, 1989). By theorizing there is a connection between abstractions and the transfer of knowledge, it is possible to develop studies to substantiate this connection. Requisite of any such study would be operationalizing what constitutes a connection. Therefore, for this study the operationalized version of Anderson's definition of knowledge transfer was the abstraction of any knowledge, information, or experiences by participants and used when trying to understand higher order concepts. The T/E DBL process is uniquely suited to foster knowledge transfer because knowledge from different content areas provides the foundation of solving real-world problems.

2. RESEARCH DESIGN

The purpose of this study was the development of an instrument to provide data of STEM content knowledge transfer. Guided by the following research questions this study utilized a case study methodology:

• In what ways does the use of a Design Log provide evidence of the transfer of STEM content knowledge while students are engaged in a technological/engineering design-based learning activity?

- RQ-S1 What phrasing of Design Log reflective prompts effectively reveal STEM content connections?
- RQ-S2 To what extent can a Design Log instrument allow a researcher to make judgments regarding the transfer of STEM content knowledge?

The conduct of this research followed a case study design, specifically a multiple case: embedded design. Technological/engineering design teams comprise the cases in this study and individual students in each team comprise the embedded unit of analysis (Yin, 2009, p. 29). For example, if two teams were being studied then they would each be one case. Individual students in each case would be the embedded unit of analysis. A case is embedded when collecting and analyzing data from each participant (unit of analysis) in each case (Yin, 2003). The criteria for a case study as outlined by Yin (2003) allows for the collection and analysis of multiple types of data in order to create an accurate picture of a phenomenon. The goal of each type of data source is to highlight a different aspect of the phenomenon. Points of convergence are identified through data triangulation. This study used a multiple case: embedded design to accommodate the process of instrument development by allowing the instrument to be developed and modified over three phases with multiple technological/engineering design teams. Triangulation of data collected from technological/ engineering (T/E) design teams and interview data collected both as a team and from individual participants (units of analysis) was conducted to identify points of convergence regarding the transfer of STEM content knowledge across all data sources.

Previous studies of knowledge transfer (Barlax & Trebell, 2008; Hill, 1997; Kelly, 2008; Kolodner, 2003, 2002; Puntambekar & Kolodner, 2005, 1998) acted as a guide in identifying adequate data sources to answer each research question across three phases of data collection and analysis. Data necessary for investigating the research questions were generated, collected, and analyzed across three distinct Phases: Phase 1: Pilot Case Study, Phase 2: Establishing Content Validity, and Phase 3: Establishing Construct Validity.

Data collection included interviews, field notes, Design Logs, and Audio/Video recordings of participant work sessions. While students worked on their T/E design activities, all data were collected concurrently providing a mechanism for the convergence of data through triangulation.

2.1. Participants

The nature of this instrument development required the participation of individuals involved in T/E design-based activities. Such individuals were readily found in departments of engineering where design is a central focus of the curriculum. Within the engineering department at a large southeastern university, undergraduate engineering students were sought, specifically targeting those in Engineering Science (ES). The ES department is uniquely suited to accommodate research investigating the transfer of STEM content knowledge in T/E design activities because of their focus on intentionally necessitating the transfer of STEM content knowledge to solve T/E design problems. ES programs "focus on imparting and using fundamental interdisciplinary skills that address engineering problems" (Puri, 2008). Students of ES programs approach problems from a theoretical level allowing them to use the interdisciplinary skills they have gained as described by Puri (2008) and make STEM content connections. Particularly immersed in T/E design are senior engineering students in ES during their required fourth year, capstone design course, which intentionally attempts to foster the use of knowledge that they have learned in their previous college courses. During this capstone course, seniors work in teams to solve a T/E design problem. Senior capstone design teams were selected to participate in Phase 1, which was the pilot study. At this particular southeastern university, sophomore ES students are also engaged in T/E design activities in teams as a way to expose them to design at an early stage in their collegiate engineering preparation. Sophomore teams were selected to participate in Phase 3 serving as the population used in establishing the construct validity of the Design Log Instrument (DLI).

2.2. Phase 1: Pilot Case Study

Phase 1 was a pilot case study conducted as a means of developing the initial DLI. Assessment of the initial DLI occurred over a period of five weeks during a T/E design activity. Two design teams were utilized, each meeting once a week for the duration of the five weeks. Concurrent collection of Audio/Video recordings and field note data occurred during each work session. At the end of each work session team interviews were conducted and DLI data were collected from each team member. Triangulation of these four data points provided the basis for iterative revisions across the five weeks. The primary means for making these revisions were the end of work session interviews. Interviews were used to collect participant feedback to evaluate the clarity of the reflective prompts. Coding of these data provided participant perceptions of the DLI and its ease of use. Based on the collective responses of all participants, modifications to the DLI improved the use of the prompts as well as increased their ability to report instances of transfer.

The purpose of this triangulation was to judge the degree to which participant responses to the DLI corresponded with the field notes and Audio/Video recording transcripts as an attempt to establish the reliability of the DLI as an independent measure of transfer. The triangulation process described above was the method used to make iterative revisions to the DLI after each weekly session with both design teams. Presented in Table 1 is a comparison of the initial and final iteration of the DLI reflective prompts.

Table 1. *Comparison of Initial and Final DLI Prompt Iterations*

Prompt #	Initial Reflective Prompts	Final Iteration of Reflective Prompts
1	Of all the tasks you have worked through during this work session, which have you started to work on but have not completed?	Look at your notes on the previous page and identify the main topics that were discussed during this work session.
2	What information did you need to search for that you did not already know and what knowledge did you already have that you used during this work session?	Considering the phase(s) you indicated on the previous page and the main topics you listed in question one, what Science, Technology, Engineering, and Mathematics (STEM) content did you know and what STEM content did you not know about each topic?
3	How did you solve any problems that arose during this work session?	List any design constraints, design trade-offs, or design failures that you were confronted with during this work session. Then explain how what you were confronted with allowed you to improve your proposal (design solution).
4	Based on the expectations for your final solution that were framed in phase 2, how does the work you completed during this work session align with those expectations?	Looking at the design constraints, design trade-offs, or design failures you listed in question three, how do those modifications affect your original proposal (design) scenario criteria?
5	How would you predict your final solution to work based on the decisions which you have made during this work session?	From the affects stated in question four, how do you predict they will influence your final proposal (design solution)? Explain your answer.

Phase 1 began by using the DLI previously developed prior to beginning the collection of data. Both design teams used this version of the DLI during the first weekly work session. Following the use of this instrument containing the initial reflective prompts, weekly iterative revisions resulted in an instrument containing the final reflective prompts as indicated in Table 1. Iterative revisions to the DLI reflect the data analysis and participant responses to the interview questions. The STEM content experts reviewed the data and reached consensus on revisions to DLI reflective prompts.

After the first week of data collection in Phase 1, 88.89% (8 of 9) of participants reported confusion and misunderstanding with the DLI. At the end of Phase 1, 100% (9 of 9) of participants reported that the DLI was clear and simple to follow. They also stated that the DLI had improved over time and flowed better. Phase 2 of this study utilized the final iteration of the DLI reflective prompts to establish content validity.

2.3. Phase 2: Establishing Content Validity

According to Hittleman and Simon (2006) in order to establish the content validity of a questionnaire, the instrument creator must "demonstrate that the specific items [criteria] or questions represent an accurate sampling of specific bodies of knowledge. Creators of instruments establish content validity by submitting the instruments' items [criteria] to a group of authorities in the content area and it is their expert opinions that determine whether the instruments have content validity" (p. 112). In this study the term criteria replaces the term item throughout. A group of three STEM content experts using the content validity process described by Yaghmaie (2003) reviewed the DLI reflective prompts to determine their accuracy to elicit participant demonstration of STEM content knowledge transfer. Experts rated each DLI reflective prompt based on its relevance, clarity, simplicity, and ambiguity (Yaghmaie, 2003) using a four-point scale: 1) strongly disagree, 2) disagree, 3) agree, and 4) strongly agree. Ambiguity was rated using a reverse scale.

Analysis of expert ratings utilized the Content Validity Index (CVI) developed by Waltz & Bausell (1983), which is the "proportion of criteria given a rating of 3 or 4 by the raters involved" if using a four point likert scale. As suggested by Yaghmaie (2003) only those criteria receiving a CVI of 0.75 or higher were suitable for the study as written.

2.4. Phase 2: Content Validity Results

During the consensus meeting, experts met to present their ratings and discuss the DLI reflective prompts. Experts took turns discussing their ratings and possible ways to improve each reflective prompt. This continued until all experts agreed on the revisions. Table 2 shows the results of the CVI ratings of each DLI reflective prompt.

Of the six reflective prompts analyzed, only Reflective Prompt 4 received a CVI below 0.75. Although results showed the remaining prompts to be content valid, experts still suggested modifications to improve their readability. Experts discussed the reflective prompts as a group to improve clarity, resulting in slight modifications (Table 3).

Table 2
Content Validity Results

Prompt #	DLI Reflective Prompt	CVI
(0)	Which phase(s) of the design process are you currently in? Please circle the phase(s).	1
(1)	Look at your notes on the previous page and identify the main topics that were discussed during this work session.	.917
(2)	Considering the phase(s) you indicated on the previous page and the main topics you listed in question one, what Science, Technology, Engineering, and Mathematics (STEM) content did you know and what STEM content did you not know about each topic?	.75
(3)	List any design constraints, design trade-offs, or design failures that you were confronted with during this work session. Then explain how what you were confronted with allowed you to improve your proposal (design solution).	.75
(4)	Looking at the design constraints, design trade-offs, or design failures you listed in question three, how do those modifications affect your original proposal (design) scenario criteria?	.50
(5)	From the affects stated in question four, how do you predict they will influence your final proposal (design solution)? Explain your answer.	.75

Note. CVI = content validity index.

Table 3
Phase 2 Revisions of DLI Reflective Prompts

Prompt #	Initial Reflective Prompts	Revised Reflective Prompts
1	Look at your notes on the previous page and identify the main topics that were discussed during this work session.	Look at your notes on the previous page, then ***identify and list*** the main topics that were discussed during this work session.
2	Considering the phase(s) you indicated on the previous page and the main topics you listed in question one, what Science, Technology, Engineering, and Mathematics (STEM) content did you know and what STEM content did you not know about each topic?	Considering the main topics ***you listed in question one***, describe what Science, Technology, Engineering, and Mathematics (STEM) content you **knew** and what STEM content you did **not know** about each topic?
3	List any design constraints, design trade-offs, or design failures that you were confronted with during this work session. Then explain how what you were confronted with allowed you to improve your proposal (design solution).	***List any design constraints, design trade-offs, or design failures*** that you were confronted with during this work session.
4	Looking at the design constraints, design trade-offs, or design failures you listed in question three, how do those modifications affect your original proposal (design) scenario criteria?	***Explain how these design constraints, design trade-offs, or design failures led you to change your proposal.***
5	From the affects stated in question four, how do you predict they will influence your final proposal (design solution)? Explain your answer.	***Given your response to question three***, what is your prediction of how each design constraint, design trade-off, or design failure will affect your final proposal? Explain your answer.

Based on the consensus meeting discussion and the expert ratings, it was determined that DLI reflective prompts needed to build off each other, making prompts more cohesive. Prompts also became more specific to guide participants regarding how to respond.

2.4.1. Reflective Prompts 3 & 4.

Reflective Prompt 4 received a CVI below 0.75 and therefore further discussion was needed to reach consensus. The original sequence of Reflective Prompts 3 and 4 seemed confusing because experts agreed that participants might not understand the difference between their proposal and their original proposal. To resolve this issue, the experts agreed that participants should simply list the design constraints, design trade-offs, or design failures in Reflective Prompt 3. In this way, Reflective Prompt 4 now asked participants to explain how each led them to change their proposal. All of these modifications resulted in a content valid, sixth iteration of the DLI for use in Phase 3 of this study.

2.5. Phase Three: Establishing Construct Validity

Construct validity of the DLI, developed through the first two phases of this study, occurred in Phase 3. In Phase 3, the content validated DLI was used during a T/E design problem spanning the first 6 phases of the T/E design process. The establishment of construct validity in this study was critical to determine the degree to which DLI reflective prompts elicited responses that align with the theoretical construct of knowledge transfer.

Phase 3 utilized two design teams working through two different design problems. Data collection occurred in Phase 3 at each team work session, which entailed Audio/Video recordings and field notes for later analysis and triangulation. At the end of each work session, time was provided for participants to make a DLI entry. Participants had five to ten minutes to respond to the DLI reflective prompts. Mid-phase (week three) and end-of-phase (week seven) interviews occurred individually with each participant to gather detailed explanations of DLI entries and clarify how participants used knowledge. Participants received their DLI at the beginning of the T/E design activity and used the same DLI throughout the project.

2.6. Interrater Reliability

An initial coding scheme was developed and tested using five raters. Data from each participating team of sophomores were analyzed independently using an established method for achieving interrater reliability. Utilizing the initial coding scheme, raters coded 10% of the data from each team, which amounted to one Audio/Video recording transcript per team (Cox, 1996; Fink, 1995; Fink & Kosecoff, 1985). Based on the results of coding by raters, a percent agreement was calculated. This measure is the ratio of the number of criteria on which the raters agreed divided by the total number of criteria: (Total number of agreements / Total number of observations) X 100. An overall percent agreement equal to or higher than 80% was desired (Cox, 1996; Fink, 1995; Fink & Kosecoff, 1985).

3. TEAM 1 DATA ANALYSIS

The design challenge for Team 1 dealt with wind energy, and they were to determine a location for a wind farm based on several determining factors. The specifics of their design challenge were as follows:

Wind Power In XXXXX: Governor XXXXXX has expressed strong interest in establishing wind farms in the state as an important new industry. One of the key areas currently under consideration for a wind farm is off the Eastern Shore of XXXXXX, in the Atlantic and on XXXXXXX. The governor has asked your engineering consulting group to examine the feasibility of these projects and prepare a brief presentation for members of the state congress who will be asked to support the project. Wind energy is subject to a number of different controversies, including technical (can it really generate enough power to be worthwhile?), environmental (will it harm native wildlife?), and social (will it be an eyesore and destroy tourism?).

Due to the nature of this design challenge, participants would only be working through the first six of nine T/E design phases. Table 4 shows the results of data analysis for Team 1 spanning six weeks.

Findings from the analysis of Team 1 data indicated that the DLI was 67% reliable with Team 1 over six weeks. As shown in Table 4 the data that is in bold/italics depicts abstractions observed, but not reported. The DLI reliability per week is shown in Table 5.

Table 4

Team 1 Consolidated Data Analysis

Week	Design Phase (Observed)	DLI Entry	Audio/Video Observation Data
1	3	Weather	Weather, Environmental, Install issues
		Efficiency figures	Highly efficient, Size vs. efficiency
		Location	Amount of area, Finite, Maximum theoretical energy, Traffic (boats)
		Cost	Cost, money, life cycle cost, cost to build, cost to stick it in, payback
		Environmental Effects	Environmental, Effects on animals, Eye sore, Tourism
		Design	Efficiency, Energy, Design, Advantages, Disadvantages
		Feasibility	Tie into the power grid, atmospheric thermal warming, convenience
2	3	Weather	Weather Patterns, Potential Wind, Average Wind Speed, Effect on TV Antennas
		Cost	Life cycle costs, Material, Recyclability, Maintenance, Break-even point
		Environmental Impacts	Environmental Impacts, Noise, Eye Sore, CO2 Production, Greenhouse Gasses, Nitrogen
			Feasibility
			Designs
			Efficiency
		Location	Available Land, Spacing, Land Analysis
3	3		***Efficiency***
		Environmental Impacts	Environmental Impacts, Killing birds, Construction, Erosion, Cleaner then coal, Endangered birds
		Location	Locations, Wind maps, Scale, Acers, Weather, Reactive Power, Transmission lines, Homes, International waters, Navy
		Design	Designs, Alternate designs, Versatility, Efficiency, Weather, Scalability
		Cost	Cost, Competitive, Becoming cheaper, Technology, Budgetary constraints, Available money
		Weather	Weather, Wind speed, Potential wind energy
4	3	Design	Designs, New Model, Metric, Maintenance, Wind VAR, Stabilization of power grid,
		Cost	Cost, Government support, Overhead cost, Comparison, Instillation over time
			Location
5	6		***Environmental Impacts***
			Cost
			Design
6	6	Cost	Cost, Cost vs. output, Cost vs. distance, Total output, Amount of turbines, Capacity
		Feasibility	Feasibility, Advantages, Stabilizing the power grid, Producing reactive power with no wind
			Efficiency
			Environmental Impacts

Note: Words in bold/italics indicate abstractions that were observed but not reported by participants.

Table 5. *Team 1 Reliability Ratio*

Work Sessions	Observed Abstractions	Reported Abstractions (DLI)	Reliability Ratio (Reported / Observed)	Average Reliability (∑ Reported / ∑ Observed)
1	7	7	100%	
2	7	4	57%	
3	6	5	83%	
4	3	2	67%	
5	3	0	0%	
6	-	-	-	
7	4	2	50%	
Total	30	20		67%

Note: Missing data (-) represents sessions where the team did not meet.

4. TEAM 2 DATA ANALYSIS

The design challenge for Team 2 dealt with creating an exercise regimen. The specifics of their design challenge were as follows:

Exercise for Bone Health: A recent report in the XXXXX raised questions about the types of exercise individuals should engage in to maintain healthy bones. Confused by the conflicting findings reported in the magazine, a group of family physicians has asked your biomechanics research group to come give a talk at their next monthly meeting. They'd like your group to give them guidelines that they can use for recommending exercise programs for their older patients in particular. Note that these doctors are general practitioners, not orthopedists or gerontologists or related specialists. They are concerned both about what kinds of exercise will help their patients and about what exercises they can reasonably expect their patients to engage in.

Due to the nature of this design challenge, participants in Team 2 also only completed the first six of nine T/E design phases. The results of data analysis for Team 2 appear in Table 6.

Findings from the analysis of Team 2 data indicated that the DLI was 70% reliable over five weeks. The DLI reliability per week is presented in Table 7.

Table 7. *Team 2 Reliability Ratio*

Work Sessions	Observed Abstractions	Reported Abstractions (DLI)	Reliability Ratio (Reported / Observed)	Average Reliability (∑ Reported / ∑ Observed)
1	2	1	50%	
2	4	4	100%	
3	-	-	-	
4	-	-	-	
5	2	2	100%	
6	5	4	80%	
7	4	1	25%	
Total	17	12		70%

Note: Missing data (-) represents sessions where the team did not meet.

5. COMBINED TEAMS 1 AND 2 DATA

With the data from Teams 1 and 2 independently analyzed, an average reliability of the DLI over the entirety of Phase 3 was calculated. The average reliability of the combined Team 1 and 2 data was 68%. Reported in Table 8 are data collected across all DLI reflective prompts and

Table 6. *Team 2 Consolidated Data Analysis*

Week	Design Phase (Observed)	DLI Entry	Audio/Video Observation Data
1	3		***Design Process***
		Exercise Rigor	Running, joints, knees, hips, energy, brisk walking, swimming, resistance, water aerobics
2	3	Supplements	Supplements, Calcium, Exercising, Genetic
		Exercise Rigor	Exercise Rigor, High Impact, Low Impacts, Older People, Power Walking, Dancing, Tennis
		Design Process	Problem statement, Steps 1/2/3, Frame the problem, Presentation, Marketing, technical, friendly version
		Exercise Constraints	Exercise Constraints, Length of time, Frequency of exercises, Physical Limitations, How strenuous, Amount of Impact
3	3	Design Process	Framed out, Criteria, Solution, Negotiation, Sources, Recommendations
		Exercise Constraints	Exercise Constraints, Access to local gyms, Implementation, aerobics classes, Swimming Pool
4	3, 4, 5	Design Process	Poster slide, Final solution, Presentation, Journals, References, Audience, Terminology, Background knowledge, Solution, Organization, Consensus
		Exercise Rigor	Exercise Rigor, Length of exercise, Frequency, Rigor, Impact level, Jumping, Pre-existing conditions, Impact, Balance
		Exercise Constraints	Exercise Constraints, Accessibility, Do at home, Running, Jumping, Frequency, Aerobic muscle strength
		Exercise Plans	Exercise Plans, Work out plan, Customizable, Categories, Jumping, Climbing stairs, Walking, Jogging, Gardening
			Age Range For Elderly Adults
5	5, 6	Design Process	Poster, Introduction, Abstract, Conclusions, Frame the problem, Objective, Method, Tables and graphs, Limitations, Requirements
			Exercise Plans
			Logistics
			Exercise Rigor

Note: Words in bold/italics indicate abstractions that were observed but not reported by participants.

all observation data (Audio/Video transcripts, field notes, interviews) per work session.

Table 8. *Combined Teams Reliability Ratio*

Work Sessions	Observed Abstractions	Reported Abstractions (DLI)	Reliability Ratio (Reported / Observed)	Average Reliability (∑ Reported / ∑ Observed)
1	9	8	88%	
2	11	8	72%	
3	6	5	83%	
4	3	2	67%	
5	5	2	40%	
6	5	4	80%	
7	8	3	37.5%	
Total	47	32		68%

Note: Missing data (-) represents sessions where the team did not meet.

Further analyses of data gathered across all seven work sessions per individual DLI reflective prompt was conducted in order to reveal the relative strength of each criteria for eliciting STEM content knowledge transfer. Findings from this analysis indicated that the majority of the abstractions occurred when participants responded to DLI Reflective Prompt 2 which asked what STEM content knowledge they knew and the knowledge they did not know. The percent abstractions found per DLI reflective prompt appear in Table 9.

Table 9
Percentage of Abstractions Found Per DLI Reflective Prompt

Prompt #	DLI Reflective Prompts	% Abstractions
1	Look at your notes on the previous page, then identify and list the main topics that were discussed during this work session.	20%
2	Considering the main topics you listed in question one, describe what Science, Technology, Engineering, and Mathematics (STEM) content you **knew** and what STEM content you did **not know** about each topic?	36%
3	List any design constraints, design trade-offs, or design failures that you were confronted with during this work session.	22%
4	Explain how these design constraints, design trade-offs, or design failures led you to change your proposal.	9%
5	Given your response to question three, what is your prediction of how each design constraint, design trade-off, or design failure will affect your final proposal? Explain your answer.	13%

It is important to note that the DLI reflective prompts were purposefully developed to align with the phases of the T/E design process. For this reason, data collected across all seven work sessions were again analyzed per T/E design process phase. Due to the nature of the design activities that participants were given, they began working in T/E Design Phase 3. Participants were initially given an identified problem and criteria for their final solution. Results of this analysis indicated that the majority of abstractions occurred during Design Phase 3, which corresponds with DLI Reflective Prompt 2. This suggests that when participants are investigating a problem they evaluate what is known and unknown, which fosters the transfer of STEM content knowledge. Similarly, when participants are tasked with choosing a solution and developing that solution, they are confronted with design constraints, design trade-offs, and design failures. To solve issues that arise in these categories participants draw on their STEM content knowledge. The percent of abstractions associated with each T/E design phase are presented in Table 10.

Table 10
Percentage of Abstractions Found Per T/E Design Phase

Design Phase #	T/E Design Process Phase Descriptions	% Abstractions
1	Identify a problem either by observation or a human need	0%
2	Frame criteria for the final solution	0%
3	Investigate what is known about the problem	71%
4	Develop alternate solutions to the problem	5%
5	Choose an appropriate solution from the alternate solutions	10%
6	Develop detailed plans for constructing your chosen solution	14%
7	Simulate or prototype your chosen solution	0%
8	Check to see if your chosen solution meets the criteria that were identified earlier	0%
9	If the chosen solution does not meet the criteria make any improvements necessary and present your findings	0%

Findings from Phase 3 data analysis led to one final revision of DLI Reflective Prompt 4. That revision is shown in Table 11.

After both design teams met for work session three, it became apparent that Reflective Prompt 4 needed to be changed. DLI responses suggested that 100% (9 of 9) of participants were not responding to Reflective Prompt 4. When asked why, during the mid-phase interviews (week three), participants reported that they did not feel as though they had a proposal to change until later in the T/E design process. When instead asked verbally during the mid-phase interviews (week three) how their thinking changed, 100% (9 of 9) of participants were able to respond to this prompt. This prompt was also the weakest DLI reflective prompt, only accounting for 9% of the total abstractions identified during Phase 3 (Table 9). At the end of Phase 3 DLI Reflective Prompt 4 changed from asking how design constraints, design trade-offs, or design failures led participants to change their proposal to how they led participants to change their thinking on the project. This change was incorporated into the final iteration of DLI Reflective Prompt 4. The final version of the DLI is shown in Appendix A.

Table 11
Final DLI Reflective Prompt Revisions

#	Initial Reflective Prompts	Final Reflective Prompts
1	Look at your notes on the previous page, then identify and list the main topics that were discussed during this work session.	Look at your notes on the previous page, then identify and list the main topics that were discussed during this work session.
2	Considering the main topics you listed in question one, describe what Science, Technology, Engineering, and Mathematics (STEM) content you **knew** and what STEM content you did **not know** about each topic?	Considering the main topics you listed in question one, describe what Science, Technology, Engineering, and Mathematics (STEM) content you knew and what STEM content you did not know about each topic?
3	List any design constraints, design trade-offs, or design failures that you were confronted with during this work session.	List any design constraints, design trade-offs, or design failures that you were confronted with during this work session.
4	Explain how these design constraints, design trade-offs, or design failures led you to change your proposal.	Explain how these design constraints, design trade-offs, or design failures led you to change ***your thinking of the project***.
5	Given your response to question three, what is your prediction of how each design constraint, design trade-off, or design failure will affect your final proposal? Explain your answer.	Given your response to question three, what is your prediction of how each design constraint, design trade-off, or design failure will affect your final proposal? Explain your answer.

6. CONCLUSIONS

The purpose of this study was to address the need for empirical evidence to support the belief that the DLI could facilitate the evidencing of STEM content knowledge transfer. To guide this investigation the following research questions were developed:

- In what ways does the use of a Design Log provide evidence of the transfer of STEM content knowledge while students are engaged in a technological/engineering design-based learning activity?
- RQ-S1 What phrasing of Design Log reflective prompts effectively reveal STEM content connections?
- RQ-S2 To what extent can a Design Log instrument allow a researcher to make judgments regarding the transfer of STEM content knowledge?

Each of these questions related to a specific aspect of the instrument and its development.

6.1. Research question sub-one (RQ-S1)

RQ-S1 dealt with development of the phrasing for the DLI reflective prompts. It asked, “What phrasing of Design Log reflective prompts effectively reveal STEM content connections?” To answer this question the DLI was tested, evaluated, and refined throughout three phases. At the conclusion of Phase 2 the DLI contained reflective prompts that were content valid and poised to test their ability for providing evidence of STEM content knowledge transfer. Testing of the DLI took place in Phase 3 where data were collected from two teams each working independently through different engineering design problems. Analysis of this data resulted in the final reflective prompt iteration (Table 11) at the end of the phase.

Based on data analysis in this study, when asking participants to reflect on their work, reflective prompts must be very specific and cohesive. Throughout this study, each reflective prompt revision became more specific to encourage participants to respond in a specific way. Data analysis of both DLI responses and interview responses provided insight into where disconnects were occurring. This process proved to be ideal because through direct feedback from participants, reflective prompts more closely represented language and content that they were familiar with while preserving the types of data that were necessary for this study. At the end of Phase 3 effective phrasing of DLI reflective prompts were identified to reveal STEM content connections.

6.2. Research question sub-two (RQ-S2)

RQ-S2 asks to what extent the DLI can allow a researcher to make judgments regarding the transfer of STEM content knowledge. Data collection in this study consisted of Audio/Video recordings, field notes, interviews, and DLI responses. Through iterative revisions of the DLI, the goal was to develop the reflective prompts so that they could aid in the independent collection of data on knowledge transfer without the need for Audio/Video recordings, field notes, and interviews.

Findings in Phase 3 of this research indicate that the DLI shows potential to be 68% reliable (Table 8) as an independent measure of knowledge transfer. This meant that 68% of the time the DLI provides similar data as the triangulation of the Audio/Video recordings, field notes, and interviews but is just below the desired 70% threshold (Cox, 2008, p. 40; Fink, 1995; Fink & Kosecoff, 1985) required for use as an independent method of data collection. Although the reliability of the DLI is nearly desirable, reflective prompts must be further developed to foster greater discussion of topics. The triangulation data provides a deep level of insight into how knowledge is used to solve problems that the DLI by itself currently does not. In order for the DLI to truly be used as an independent measure of STEM content knowledge transfer, this insight must be present in DLI responses. Further refinement and development may improve the reliability of the DLI and the ability of the reflective prompts to elicit responses that not only provide evidence of STEM content knowledge transfer but also explain those instances.

6.3. Overarching research question

The overarching question of this study was, “In what ways does the use of a Design Log provide evidence of the transfer of STEM content knowledge while students are engaged in a technological/engineering design-based learning activity?” Data analyzed to answer each individual sub question provided direction in answering the overarching question. As this study progressed the DLI required fewer substantial changes. This indicated that as time went on the DLI was more accurately providing evidence of knowledge transfer. At the end of Phase 3 the DLI showed the potential to be 68% reliable as an independent measure of STEM content knowledge transfer. Though this shows a degree of success with the instrument, it is still not reliable enough for use as an independent source of data. Participants were providing evidence of STEM content knowledge transfer in their DLI responses, but they were not providing as many instances as were identified in the observation data (Audio/Video recordings and Field Notes). Participants also gave a simple explanation of topics discussed during their team work sessions which was not as robust as what the observation data provided. There are several plausible reasons for the gap between the observed and reported abstractions. Knowledge abstraction is more likely to occur in some T/E design phases than in others. It is plausible that participants did not recognize that they were abstracting knowledge but rather thought they were applying knowledge from a previous design phase. For example, 71% of the total abstractions occurred during T/E Design Phase 3, which dealt with investigating the problem. Participants used the abstracted knowledge gained during this phase and applied it to develop alternate solutions during T/E Design Phase 4. Although participants did not report abstractions during this design phase, observation data shows that participants were abstracting knowledge, causing the gap between observed and reported abstractions. It is also possible that motivation affected participant’s willingness to respond to DLI reflective prompts. The DLI required participants to do additional work at the conclusion of each work session. This may have invoked a level of fatigue in participants, which caused them to respond to reflective prompts without the necessary effort required to provide meaningful data. For these reasons, assigning STEM content codes to abstractions found in the DLI responses was difficult without the accompanying observation data.

Participants in both Phase 1 (pilot study) and Phase 3 (implementation) reported that the DLI provided a valuable record of design decisions throughout the T/E design process. During both mid-phase (week three) and end-of-phase (week seven) interviews conducted during implementation, 100% of participants reported that the DLI allowed them to keep track of past decisions and reflect on them while making new decisions. This level of reflection improved the ability of participants to make informed decisions and to consider the positives and negatives of each. Specifically in Phase 3, as an unintended outcome, the DLI allowed participants to monitor their own learning and acted as a guide through the T/E design process. In this way, there is potential to use the DLI as an instructional tool as well as a method for collecting data.

While the DLI is not yet ready to be used as an independent measure of STEM content knowledge transfer at this time, it does show promise for providing such data independently. With future iterations, the reliability of the DLI can increase as an independent instrument. The current target audience of this instrument is students in undergraduate programs engaged in T/E design activities. The reliability of this instrument is also bound to the studied context and therefore needs further development in other contexts to verify the reliability.

7. IMPLICATIONS

The findings of this study have implications for the profession of Technology Education, T/E design based learning, and on knowledge transfer research.

7.1. Technology Education

Studies such as this show that T/E design is a valuable pedagogical approach to teaching and learning that fosters deep understanding in students. If Technology Education hopes to compete with the other STEM disciplines in the research arena these types of cognitive inquires will need to be a large part of our field moving forward. As Technology Education struggles to find its footing during the current push to incorporate more engineering content into K-12 education, this study presents preliminary evidence that Technology Education offers a general literacy based approach to learning T/E design (Cajas, 2001; ITEA, 2000; Wells, 2010, 2006; 2008). Technology Education seeks to take a broader look at T/E design and develop students as literate members of society that can solve problems in their everyday lives. By conducting research into the cognitive aspects of how students approach and work through T/E design problems, we as a profession can expand what we know and how we present design to foster such literacy.

7.2. T/E design based learning

The combined T/E design based learning (DBL) process depicted and refined in this study followed the Integrative STEM Education T/E DBL Pedagogical Model developed by Wells (2009). The Wells model "depicts the integration of technological/engineering design based learning with scientific inquiry as an integral element of the design based instructional approach for intentionally teaching science and technology/engineering content and practices" (p. 1) as a strategy to foster knowledge transfer, and served as the basis for the DBL process used in this study. Abstraction of each process allowed them to be blended into a single approach, with application in each independent discipline. By blending inquiry and T/E design, students are presented with a process that can be used in either a science, technology, or engineering classroom. By intentionally blending the identical elements of each process, the transfer of STEM content knowledge increases in likelihood. Thorndike (1901) described this phenomenon with his identical elements theory, which states, as the elements of a process become identical, the greater the likelihood that knowledge will transfer between them.

7.3. Knowledge transfer research

The illustration of the transfer paradigm (abstraction + situated environments = transfer) depicted in this study builds on previous transfer research and goes a step further to specifically look at transfer in a combined T/E design process. Studies, such as the one presented here, help in validating this perspective. T/E design based learning provided a unique lens as the context for this study and allowed the researcher to take previous work and utilize it in a novel situation. From this investigation the T/E design process is an ideal context for studying the transfer of knowledge because T/E design inherently requires students to use knowledge learned from many disciplines to solve design problems.

8. RECOMMENDATIONS FOR FURTHER RESEARCH

The findings of this study provide a good foundation for further research using the DLI in T/E design based environments.

8.1. The Design Log Instrument

Based on the reliability ratio, the DLI still needs further development. A larger scale study would help to achieve a higher level of reliability and development. With more participants, a broader sample would be possible with differing backgrounds, which would allow for increased reliability of the instrument. In addition, continuing to develop the DLI in a context outside of engineering, specifically in a Science or Technology Education classroom, would increase its reliability. Also, using the DLI with students at different grade levels such as with high school Technology Education students would provide opportunity for further development. During Phase 3 of this study, the DLI was used with sophomore engineering science students who were creating engineering proposals. Future studies, should involve students actually designing some product rather than simply making a recommendation.

8.2. Professional development

Investigation into the DLI as a teaching tool would provide a foundation for professional development regarding the transfer of knowledge during a T/E design activity. Teachers would learn how the DLI could increase student learning and foster the transfer of knowledge. Teachers would see the degree of utility that the DLI offers. This includes the importance of using an instrument such as the DLI to assess student learning. The DLI provides students with a means of being reflective and recording their thought process while working on T/E design activities. These reflections can act as a record of student learning over time.

8.3. Knowledge transfer research

Many researchers investigating knowledge transfer have expressed fundamental problems with its study. Those fundamental problems range from whether or not transfer actually exists (Detterman, 1993) to how a researcher can claim to witness transfer occurring (Carraher & Schliemann, 2002). Barnett and Ceci (2002) concluded that a century of research on transfer has made little progress in resolving its fundamental questions, and Schoenfeld (1999) identified it as one of the major challenges of educational theory in the 21st century. Findings from this study present preliminary evidence to substantiate the potential for researching knowledge transfer in technology education. A potential way of witnessing transfer occurring is through the research design presented in this study. By using a Design Log Instrument in concert with Audio/Video recordings, field notes, and interviews it is possible to witness transfer. With further refinement, it may be possible to increase this potential.

Although, the DLI was only 68% reliable, it still received many meaningful changes that improved its reliability over time. This means with further research the DLI can improve and increase its reliability. This also shows potential for studying transfer in a T/E design based context. T/E design provides an ideal context for studying the transfer of knowledge because students must inherently use knowledge from many disciplines to solve problems.

In addition, as suggested by the correlation of abstractions between the DLI and the T/E design process, specific T/E design phases can be targeted when doing research in this context.

9. REFERENCES

American Association for the Advancement of Science (1989). Science for All Americans. New York: Oxford University Press.

American Association for the Advancement of Science (1993). Benchmarks for science literacy. New York: Oxford University Press.

Anderson, J.R. (2005). Cognitive psychology and its implications. New York: Worth.

Barlex, D. & Trebell, D. (2008). Design-without-make: challenging the conventional approach to teaching and learning in a design and technology classroom. International Journal of Technology and Design Education. Springer

Barnett, S. M., & Ceci, S. J. (2002). When and where do we apply what we learn? A taxonomy for far transfer. Psychological Bulletin, 128(4), 612–637.

Barrows, H.S. (1986). A taxonomy of problem-based learning methods. Medical Education, 20, 481-486.

Cajas, F. (2001). The science/technology interaction: Implications for science literacy. Journal of Research in Science Teaching, 38(7), 715-729.

Carraher, D.,& Schliemann, A. D. (2002). The transfer dilemma. Journal of the Learning Sciences, 11(1), 1–24.

Cox, J. (2008). Your opinion, please: How to build the best questionnaires in the field of education. Thousand Oaks, CA: Corwin Press, Inc.

Cox, J. (1996). Your opinion, please: How to build the best questionnaires in the field of education. Thousand Oaks, CA: Corwin Press, Inc.

Detterman, D. K. (1993). The case for the prosecution: Transfer as an epiphenomenon. In D. K. Detterman & R. J. Sternberg (Eds.), Transfer on trial: Intelligence, cognition, and instruction (pp. 1–24). Norwood, NJ: Ablex.

Dunham, T., Wells, J., & White, K. (2002). Biotechnology education: A multiple instructional strategies approach. Journal of Technology Education, 14(1), 65-81.

Engineering Accreditation Commission. (2004). Criteria for Accrediting Engineering Programs. Baltimore, MD.

Fink, A, & Kosecoff, J. B. (1985). How to conduct surveys: A step-by-step guide. London, England: SAGE Publications, Ltd.

Fink, A. (1995). The survey handbook. Thousand Oaks, CA: Sage Publications, Inc.

Fuchs, L. S., Fuchs, D., Prentice, K., Burch, M., Hamlett, C. L., Owen, R., et al. (2003). Explicitly teaching for transfer: Effects on third-grade students' mathematical problem solving. Journal of Educational Psychology, 95(2), 293–305.

Gentner, D., Loewenstein, J.,&Thompson, L. (2003). Learning and transfer: A general role for analogical encoding. Journal of Educational Psychology, 95(2), 393–408.

Gentner, D., & Markman, A. B. (1997). Structure mapping in analogy and similarity. American Psychologist, 52, 45–56.

Gentner, D., & Medina, J. (1998). Similarity and the development of rules. Cognition, 65, 263–297.

Gick, M. L., & Holyoak, K. J. (1980). Analogical problem solving. Cognitive Psychology, 12, 306-355.

Gick, M. L., & Holyoak, K. J. (1983). Schema induction and analogical transfer. Cognitive Psychology, 15, 1-38.

Hill, R. B. (1997). The design of an instrument to assess problem solving activities in technology education. Journal of Technology Education, 9(1), 31-46.

Hittleman, D. R, & Simon, A. J. (2006). Interpreting educational research (4th ed.). Upper Saddle River, NJ: Merrill Prentice Hall.

Hutchinson, J. & Karsnitz, J. R. (1994). Design and problem solving in technology. New York, NY: Glencoe McGraw-Hill.

International Technology Education Association (2000). Standards for technological literacy: Content for the study of technology. Reston, VA: ITEA.

Kelly, T. R. (2008). Cognitive processes of students participating in engineering-focused design instruction. Journal of Technology Education, 19(2).

Kolodner, J.L., Camp, Crismond, D., Fasse, B., Gray, J., Holbrook, J., Puntambekar, S., Ryan. (2003). Putting a student-centered Learning by DesignTM curriculum into practice: Lessons learned. Journal of the Learning Sciences, 12, 485–547.

Kolodner, J. L. (2002). Facilitating the learning of design practices: Lessons learned from an inquiry into science education. Journal of Industrial Teacher Education, 39(3).

National Academy of Engineering. (2004).The Engineer of 2020: Visions of Engineering in the New Century. Washington, DC: National Academic Press.

National Council of Teachers of Mathematics (2000). Principles and standards for school mathematics. VA: NCTM.

National Research Council. (1996). National science education standards. Washington, DC: National Academy Press.

Puntambekar, S. & Kolodner, J. L. (2005). Toward implementing distributed scaffolding: Helping students learn science from design. Journal of Research in Science Teaching. 42(2), 185-217.

Puntambekar, S. & Kolodner, J.L. (1998). Distributed scaffolding: Helping students learn in a learning by design environment. In A.S. Bruckman, M. Guzdial, J.L. Kolodner, & A. Ram (Eds.), ICLS 1998, Proceedings of the international conference of the learning sciences (pp. 35–41). Charlottesville, VA: AACE.

Puri, I. K. (2008). Welcome from the department head. Engineering sciences and mechanics website. Retrieved May 14, 2010.

Raizen, S. A., Sellwood, P., Todd, R. D., and Vickers, M. (1995). Technology education in the classroom. San Francisco: Jossey-Bass Publishers.

Reed, S. K. (1993). A schema-based theory of transfer. In D. K. Detterman & R. J. Sternberg (Eds.), Transfer on trial: Intelligence, cognition, and instruction (pp. 39–67). Norwood, NJ: Ablex.

Reed, S. K., Ernst, G. W., & Banerji, R. (1974). The role of analogy in transfer between similar problem states. Cognitive Psychology, 6, 436-450.

Rutherford, J. F. & Ahlgren, A. (1990). The mathematical world. In Science for All Americans. New York: Oxford University Press

Schoenfeld, A. H. (1999). Looking toward the 21st century: Challenges of educational theory and practice. Educational Researcher, 28(7), 4–14.

Singley, M. K.,&Anderson, J. R. (1989). The transfer of cognitive skill. Cambridge, MA: Harvard University Press.

Thorndike, E. L., & Woodworth, R. S. (1901). The influence of improvement in one mental function upon the efficiency of other functions. Psychological Review, 8, 247-261.

Waltz, C. F., & Bausell, R. B. (1983). Nursing research: Design, statistics and computer analysis (2nd ed). Philadelphia, PA: Davis Company.

Wells, J. (2013). Integrative STEM education at Virginia Tech: Graduate preparation for tomorrow's leaders. Technology and Engineering Teacher, 72(5), 28-35.

Wells, J. (2010). Research on teaching and learning in science education: Potentials for technology education. In P. Reed & J. LaPorte (Eds.), Research in Technology Education (pp. 182-202). Council on Technology Teacher Education. Reston, VA: ITEA.

Wells, J. (2009). Integrative STEM education T/E DBL pedagogical model. Paper presented in STEM Education Pedagogy (EDCI 5774), Integrative STEM Education, Virginia Tech, Blacksburg, VA.

Wells, J. (2008, November). STEM Education: The potential of technology education. Paper presented at the 95th Mississippi Valley Technology Teacher Education Conference, St. Louis, MO.

Wells, J. (2007a). Emerging technologies: Toward biotechnology literacy. Paper presented in Biotechnology literacy: PBL Activities (EDCI 5774), Integrative STEM Education Virginia Tech, Blacksburg, VA.

Wells, J. (2007b). STEM education: Research priorities. Paper presented in STEM Education Research (EDCI 5774), Integrative STEM Education, Virginia Tech, Blacksburg, VA.

Wells, J. (2006). Integrating STEM education pedagogies. Paper presented in STEM Education Pedagogy (EDCI 5774), Integrative STEM Education, Virginia Tech, Blacksburg, VA.

Yaghmaie, F. (2003). Content validity and its estimation. Journal of Medical Education.

Yin, R. K. (2009) Case study research: Design and methods fourth edition. Thousand Oaks, CA:
SAGE Publications.

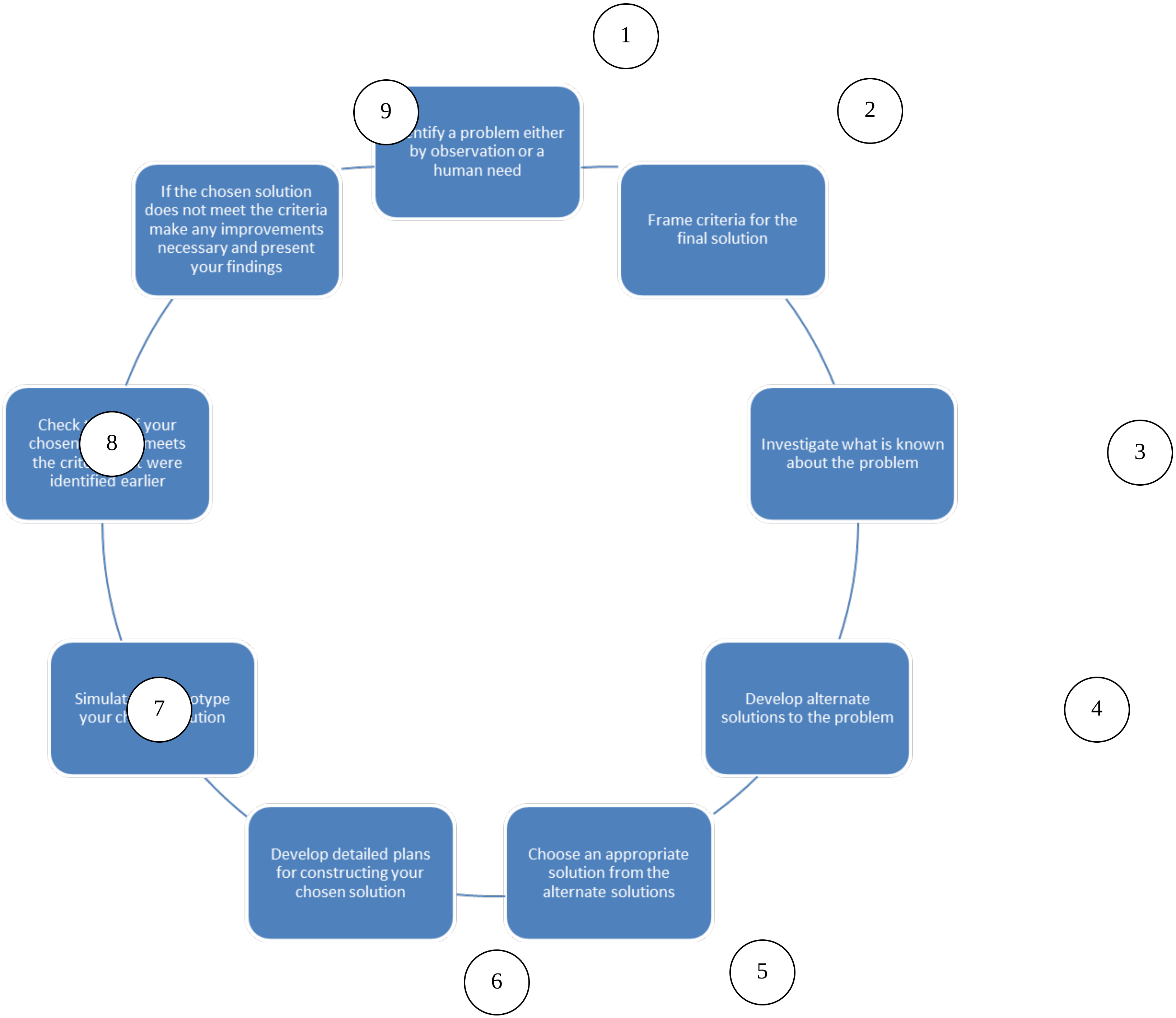
Yin, R. K. (2003) Case study research: Design and methods third edition. Thousand Oaks, CA: SAGE Publications.

10. APPENDIX A: FINAL DESIGN LOG INSTRUMENT

Design Log

Design Project: ______________________

Name: ______________________________

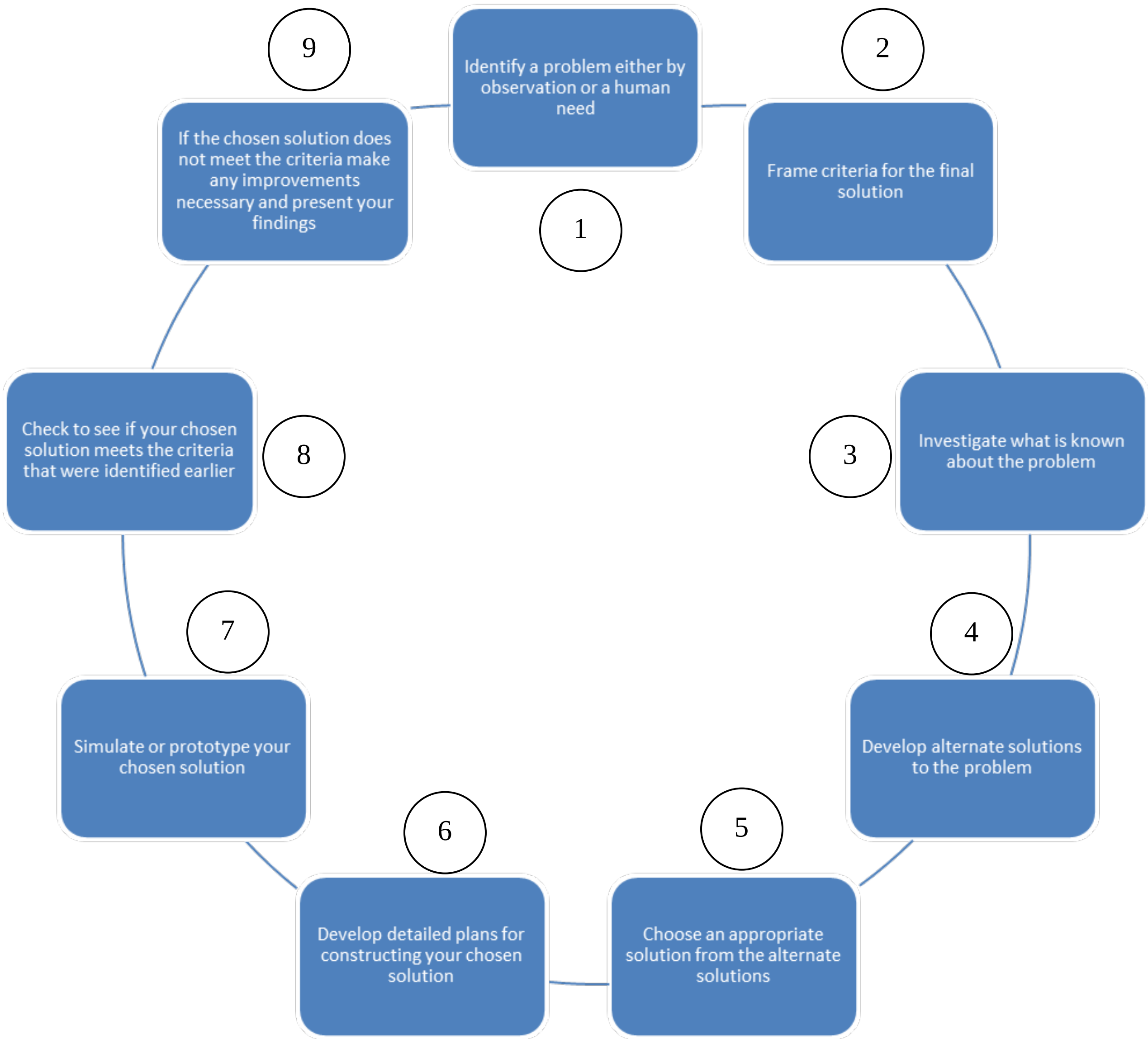

1
9
ntify a problem either by observation or a human need
2
If the chosen solution does not meet the criteria make any improvements necessary and present your findings
Frame criteria for the final solution
8
identified earlier
Investigate what is known about the problem
3
Develop alternate solutions to the problem
4
7
Develop detailed plans for constructing your chosen solution
Choose an appropriate solution from the alternate solutions
6
5

Background:
Design and Inquiry are processes that we use every day to either solve a human need or better understand the world around us. Design helps to solve human problems and recreate a world that fits our needs. In this effort, we use tools and materials to purposefully construct artifacts and systems that meet those needs. Inquiry helps to better understand the natural world and make sense of it. To make sense of the natural world experiments are conducted that are meant to answer some hypothesis about how a natural phenomenon occurs. Design and Inquiry have a unique relationship in that Inquiry is an inherent process within design. The image found on the previous page and on all subsequent pages is a combined process incorporating both elements of design and inquiry. As you go through the formal process of design mini-inquiry experiments occur to better understand how certain design considerations will work in the system. An example could be generating a hypothesis regarding the tensile strength of a material and then testing that hypothesis before incorporating that material into the design.

Directions:
At the beginning of each work session, open to a new Design Log page. Here you will find a space to take notes while you work. These notes are meant to help you answer the prompting questions at the end of your work session. At the conclusion of your work session take five to ten minutes to respond to the prompting questions. Begin by identifying which phase(s) of the design process you are currently engaged in. Do this by circling the phase(s) on the Technological Design/Inquiry Loop found on the same page as the notes, then respond to the questions. Respond to the questions to the best of your ability and as completely as possible. When you are done please sit quietly until everyone has finished.

Notes:

Which phase(s) of the design process are you currently engaged in? Please circle the phase(s).



1. Look at your notes on the previous page, then identify and list the main topics that were discussed during this work session.

2. Considering the main topics you listed in question one, describe what Science, Technology, Engineering, and Mathematics (STEM) content you **knew** and what STEM content you did **not know** about each topic?

Content I Knew	Content I Did Not Know

3. List any design constraints, design trade-offs, or design failures that you were confronted with during this work session.

4. Explain how these design constraints, design trade-offs, or design failures led you to change your thinking of the project.

5. Given your response to question three, what is your prediction of how each design constraint, design trade-off, or design failure will affect your final proposal? Explain your answer.