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SCOPE Process: Fostering Students' Design Outcome Effectiveness

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There is evidence that teachers can develop students' cognitive and metacognitive skills during design experiences using the SCOPE process.

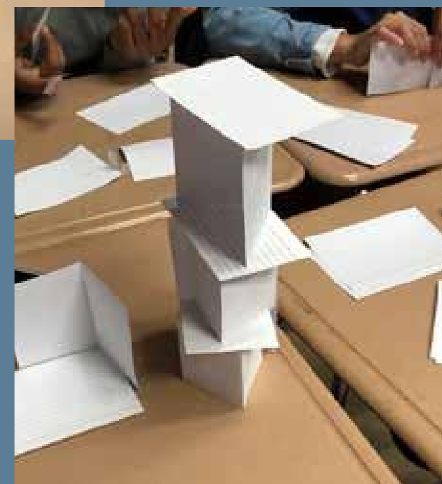
by Andrew J. Hughes and Cameron D. Denson

Introduction

The purpose of this article is to help Technology and Engineering Educators scaffold engineering design and problem-solving experiences so that students taking technology and engineering courses will develop an improved ability to design. Technology and Engineering Education (T&EE) seems to increasingly focus on problem solving, design, and engineering. T&EE is not the only discipline with this focus. Science Education is similarly focused on problem solving, design, and engineering. The fact that both Science and T&EE are similarly focused on the teaching and learning of engineering begs the question of what separates technology and engineering educators from science educators in the teaching of engineering? Lewis (2004) cautioned that the introduction of engineering signaled the discipline turning away from more practical, blue-collar knowledge, towards white-collar academic traditions. Lewis (2004) highlighted John Dewey's argument that manual training was a gateway for students to integrate math and science.

The T&EE discipline is better suited to teach engineering by a strengthened connection with characteristics that make the discipline significant and unique, like shop skills, craftsmanship, technological literacy, and the tacit knowledge and skills developed through applying sound theories during practical hands-on learning. These connections help solidify T&EE importance with teaching and learn-

ing of engineering. Additionally, technology and engineering educators need to learn from and implement research-based interventions designed to improve the teaching and learning of engineering. A research-to-practice model, like implementing research-based models and interventions presented in the *Journal of Technology Education (JTE),* can provide technology and engineering educators with the tools needed to teach engineering design better. Research illustrates that improving students' ability to solve ill-structured, open-ended design problems only happens through a well-planned, structured, and scaffolded instructional process with engaging hands-on, minds-on student learning experiences.



Design

"The subject [of design] seems to occupy the top drawer of a Pandora's box of controversial curriculum matters... Even 'design' [teachers]—those often segregated from [academic content teachers] by the courses they teach—have trouble articulating this elusive creature called design" (Evans et al., 1990 as cited by Dym et al., 2005). Learning to design requires a scaffolded approach fostering development of cognitive and metacognitive abilities used to solve multi-faceted problems that have "multiple levels of interacting components within a system that may be nested within or connected to other systems" (Lammi & Becker, 2013, p. 55). The sequencing of engineering design problem solving throughout PK-12 education starts with well-structured design experiences progressing with increased ambiguity, number of plausible solutions, problem depth, and ends with open-ended, ill-structured, and ill-defined problems (Denson & Lammi, 2014). Scaffolding engineering design experiences enables both the students and teacher to become steadily more comfortable with design complexity, multiplex design processes, and challenging problems.

Design is an essential theme in technology and engineering education classrooms, yet with the release of the *Next Generation Science Standards*, design has increasingly become a theme in science education classrooms. Additionally, most classrooms with instruction centered around design are taught by teachers not credentialed in science, math, or technology education; but rather, subjects like art, business, history, music, as well as other subjects, especially at the middle school level. There is growing momentum to situate engineering design experiences in classrooms taught by teachers who do not have related industry experience or a technology and engineering education background (NGSS, 2013). Teachers who lack the appropriate pedagogical background will experience challenges in effectively introducing students to engineering design experiences. More poignantly, students will not adequately develop design skills and abilities unless teachers are adequately prepared to offer scaffolded development thorough sequenced design experiences.

Design Instruction

Based on the research literature related to design, students' design abilities do not progress much through school-based design experiences (Becker et al., 2012). This article intends to present a scaffolded approach to the teaching and learning of design to address students' design-ability development. When design is taught, especially by those without adequate training, students' engineering design experiences are more likely to be unfocused, lacking pedagogical structure, disengaging, inauthentic, and debatably do not help students develop the underlying skills or abilities associated with improved design competence. Engineering design experiences in T&EE have the potential to be the exact opposite, especially when technology and engineering educators are provided with the tacit knowledge and skills to thoroughly apply research-based theories during practical hands-on learning. Technology and Engineering Education's approach to teaching design needs to be scaffolded but also focused on cognitive development, tool skills, measurement, geometric construction, manufacturing, instrumentation, testing and analysis, application of mathematical and scientific theories, and many other skills and abilities. Technology and engineering educators should strive to combine design experiences with adequately challenging practical hands-on experiences that connect student thinking and doing.

Design is a challenging complex task that requires both thinking and hands-on skills and abilities. The thinking involved during the design process is often related to broad terms that encompass a larger number of underlying skills and abilities. Such terms as systems thinking, problem scoping, modeling, experimenting, reflecting, and evaluating are just some of the skills that are implemented during the design process. These skills need to be embedded but also explicitly emphasized for students during design experiences. Technology and engineering educators will need to explicitly focus on the development of cognitive and metacognitive abilities to help students manage the complexity of design experiences (Table 1). The process of developing cognitive abilities requires the teacher to have students focus on problem scoping, generating alternative solutions, estimating (i.e., predicting), modeling, experimenting, and continuous evaluation (i.e., iterating). While the development of metacognitive abilities requires focus on reflection, planning, information gathering (i.e., information management), and knowledge (implying declarative, procedural, and/or conditional knowledge). Technology and engineering educators will foster students' abilities by knowing the underlying skills, understanding the interconnectedness of these skills, and the recommended approaches for developing cognitive and metacognitive skills within the learning environment. There is evidence that teachers can develop students' cognitive and metacognitive skills during design experiences using the SCOPE process.

SCOPE Process

SCOPE is an acronym for Study, Criteria, Organize, Predict, and Evaluate. The SCOPE process is designed to help students slow down and thoroughly think through the design experience by studying the design situation, identifying the problem, identifying constraints and requirements, gathering and organizing information, making predictions based on design decisions, and evaluating and selecting the best approach based on information analysis (Table 2). The SCOPE process is intended to be used with any design experience. All design experiences should start with the SCOPE process to improve outcome effectiveness. The SCOPE process is designed to promote students' success throughout any design experience. Additionally, the SCOPE process should be continuously revisited throughout iterative design experiences. The SCOPE process helps to develop students' cognitive and metacognitive abilities by connecting their thinking with their actions during design experiences. The SCOPE process can be used in conjunction with any design process the teacher decides to use and does not replace the design process.

When using the SCOPE process, a student will begin by studying the problem, which is the first part of any design experience. The "How" column in Table 2 suggests how the student will go about each stage of the SCOPE process. The How column suggests many items at each stage, but these suggestions are not all-encompassing of what happens at each stage of the SCOPE process. The "Tool" column in Table 2 provides examples of tools that students can use to record and more thoroughly analyze their thinking related to each stage of the SCOPE process. Again, the tool column suggests a few tools, but these are not the only tools that can be used to record and analyze ideas from each stage of the SCOPE process. These tools are additionally helpful in many ways including helping students keep track of progress in longer design experiences, remembering decisions that were made and reasons why, and producing accessible artifacts.

Table 1

Defining Cognitive and Metacognitive Skills

Ability Underlying Skills	**Definitions**
Cognition	
Problem Scoping (i.e., Problem Framing)	Aspects of design involving identifying criteria, constraints, and requirements; framing problem goals or essential issues; gathering information; and stating assumptions about information gathered.
Alternative Solution	Thinking of potential solutions, experimenting with solution ideas, and thinking of ways to address an impasse.
Estimation/Prediction	Focusing on important factors; using data to inform; making informed decisions. Thinking before acting.
Modeling	Conceptual, Graphical, Mathematical, and Working Models
Experimentation	Robust procedure to check ideas and make determinations.
Continuous Evaluation (i.e., iteration)	Repetitive process of analysis. Transitioning through and between stages of design.
Metacognition	
Declarative Knowledge	Knowledge about a person's own cognitive strategies, skills, and abilities.
Procedural Knowledge	How to use strategies and techniques to increase performance and accomplish cognitive tasks.
Conditional Knowledge Planning	When and why to use strategies for accomplishing tasks. Ability to select appropriate strategies, set goals, and allocate resources.
Monitoring (i.e., self-questioning)	Assessing cognition and strategy effectiveness.
Organizing (i.e., information management)	The use of cognitive strategies and techniques to manage information. Information management is the active process of organizing, elaborating, summarizing, and selectively focusing on important information for mental restructuring due to cognitive dissonance.
Debugging	Identify and correct errors and assumptions about tasks and implemented strategies.
Reflecting	Analysis of performance and strategy effectiveness.

Table 2

SCOPE Process

What	How (suggestions)	Tool Examples for Recording Thoughts/Ideas
S: Study; the problem carefully.	Read Carefully. Clarify; look up any words or terms you do not understand. Self-question: What am I being asked to do? What is the problem? Re-state the problem in your own words. Explain the problem to someone.	System Map/Analysis Problem Statement Affinity Diagram Checklists
C: Criteria; what are the criteria for success?	What are the constraints, criteria, or requirements of the design? Make a list of requirements. Verify the list of requirements.	Perception Analysis Check Sheet Pareto Chart
O: Organize; what information do you have?	What information do you have? What does your information tell you about the problem? What options do you have? What can you control or adjust? What can you not control or adjust?	Pert Chart Lotus Diagram If...Then Consensogram
P: Predict; what predictions can you make?	What predictions can you make about each approach? How might doing X, Y, or Z affect the outcome success? What is your plan? Is this plan feasible?	Correlation Chart Process Decision Program Chart
E: Evaluate; which approach seems like it would yield the best result(s)?	Which approach seems like it would yield the best result(s)? What assumptions have you made? Select the approach that best seems to meet the criteria AND addresses the problem you identified.	Decision Matrix T-chart

Tower Design Challenge

It is important to remember that design experiences need to be scaffolded and progressive, from simple to increasingly complex problems over time. It should also be noted that the Tower Design Challenge is situated along the spectrum from well-defined to ill-defined engineering design challenges. The SCOPE process is applicable for all design experiences along this spectrum. Over time, as the students and teacher become increasingly comfortable with more complex problems, the teacher can begin to scaffold more complex design scenarios. The ill-defined end of the spectrum will have students define and solve their own problems in open-ended experiences. As the teachers look to introduce increasingly complex design challenges in the classroom, they will need to work collaboratively with their students in order to develop more sophisticated assessment criteria (Denson & Lammi, 2014). The tools used to document students' thinking as well as other student documents like engineering design notebooks, modeling artifacts, and students' justifications for design decisions can be used when appropriate to assess students' design learning.

Designing a tower given limited materials is a common design problem in middle and high school design experiences as well as engineering teacher professional developments. The tower design problem presented here is situated near the beginning of a spectrum from well-defined to ill-defined engineering design challenges. The tower design challenge asks for individuals to design and construct the tallest note card tower that will hold the most weight being placed on top of it before failure. The design challenge further explains that (1) participant is given 20 minutes to design and build, (2) the tower must be self-supporting during measurement, (3) material used is associated with a cost, and (4) the individual with the lowest score using the equation provided wins. Small note cards, 4″ by 6″, cost 3 points each. Large note cards, 5″ by 8″, cost 5 points each. Each inch of tape costs 10 points. The score equation is as follows: score = ((amount of tape in inches x 10) + (# of small note cards x 3) + (# of large note cards x 5) – (height of tower in inches) – (amount of weight held in pounds)).

In this case, understanding the tower challenge is more difficult than it might initially seem, emphasizing the importance of utilizing the SCOPE process. When reading the problem, it seems to suggest that both a tall tower and a tower that will hold the most weight are equally important. What is not immediately noticeable is that height of the tower and the weight the tower will hold are inversely proportional, especially considering the 20-minute time limit. During the tower design challenge students are scored based on the score equation. However, without the SCOPE process, students may completely ignore the score equation, starting to build a tower without fully understanding the problem. The SCOPE process helps students spend more time thinking about and analyzing the problem.

Conclusion

As researchers, we have witnessed a disturbing trend of student engineering design experiences that in many cases lack pedagogical structure including not adequately scaffolding the experience, resulting in an unfocused, disengaging, and inauthentic experience that may negatively impact students' development of underlying skills or abilities associated with design. The authors would hope that engineering design experiences in Technology and Engineering Education are the exact opposite. There is need for more empirically-based studies that investigate the effectiveness of design interventions to help develop students' cognitive and metacognitive abilities. It is our hope that the SCOPE process will be added to the lexicon of engineering design experiences in K-12 environments. We encourage readers to create their own research designs using research-based models (including SCOPE) as the field seeks to advance knowledge in the engineering education milieu. Early results from the implementation of the SCOPE process in facilitating middle and high school students' engineering design experiences provide evidence that the process is effective in scaffolding the experiences for students. More research is needed to understand the most effective evaluation tools for educators who seek to implement the SCOPE process in their classrooms. It is our hope to work with more practitioners willing to implement the SCOPE process in their classrooms. As the field of T&EE struggles to keep a foothold on its content in the 21st Century it is important that the field shines an iridescent light on all the things that we do well, including teaching problem-solving skills. This light is strengthened when scholars and practitioners work together to form a didactic learning community.

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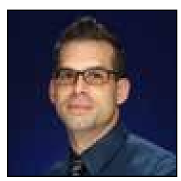

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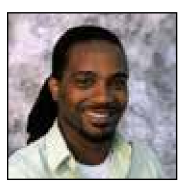

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Explaining the SCOPE Process and Tower Design Activity

The process designers use during the initial stages of design is directly related to the success of design solutions. Expert engineers sort problems based on underlying concepts. Engineering students are distracted by surface details that lead to using inappropriate solution strategies. Incorrect problem definition inevitably leads to incorrect solution, both because students are misled by faulty conception of the problem and because they fail to realize that it is faulty, a combination of cognitive and metacognitive breakdown. This is exemplified by technology and engineering educators spending insufficient amounts of time on disposition, cognitive, and metacognition skill development while focusing primarily on knowledge and problem-solving techniques.

The SCOPE process is designed to help students slow down and thoroughly think through the design experience by studying the design situation, identifying the problem, identifying constraints and requirements, gathering and organizing information, making predictions based on design decisions, and evaluating and selecting the best approach based on information analysis. SCOPE is an acronym for Study, Criteria, Organize, Predict, and Evaluate. The SCOPE process is intended to be used with any design experience. All design experiences should start with the SCOPE process to improve outcome effectiveness. The SCOPE process is designed to promote students' success throughout any design experience. Additionally, the SCOPE process should be continuously revisited throughout iterative design experiences.

In the Tower Problem-Solving Activity students are distracted by many items including the 20-minute time limit and equation, just to name two. When students are given this problem and without using the SCOPE process, a significantly lower percentage of the students will develop the most optimized answer, mostly related to surface-level details or distractions. If you remove any of these distractions, like not having students work in a group, the success rate will increase. Why does this happen? Students are not spending a significant enough amount of time where thinking is involved, specifically studying the design situation, identifying the problem, identifying constraints and requirements, gathering and organizing information, making predictions based on design decisions, and evaluating and selecting the best approach. The Tower Problem-Solving Activity is used as an introductory activity to help students learn to work with distractions and still develop a successful answer. Rather than removing distractions that will always be present, it is better to help students utilize the SCOPE process to enhance their ability to successfully solve engineering design problems. The students are given the knowledge needed to develop the best answer to the Tower Problem-Solving Activity: the equation. However, without the SCOPE process, students ignore the equation and implement faulty problem-solving techniques. Based on the equation, the best answer is not building the tallest tower; the best answer is building a tower that will support the most weight. The height of the tower and weight the tower will hold are inversely proportional.

If you look at the equation while thinking through possible solutions, you should see that the tallest the tower could be is the height of the classroom, maybe 120 inches. Again, if you build a tower that is 120 inches tall, it will likely not hold much weight before failure. However, if you build a short, even paper-thin tower, it will hold more than 120 pounds without failing. Based on the constraints, including the time limit and equation, the most optimized answer is to lay a few note cards flat on the floor in a way that will allow the weight to be stacked on top.

Tower Problem-Solving Activity

Individually you are to design and construct the tallest note card tower that will withstand the most weight being placed on top of it before failure. You will have 20 minutes to design and build the tower. Each material used during the construction of the tower is associated with a point value.

Small Note Card	3 Points
Large Note Card	5 Points
1 inch of Tape	10 Points

Scores will be calculated by:
Score=(# inches of tape x 10)+(# of small note cards x 3)+(# of large note cards x 5)-(height of tower [in inches])-(amount of weight held [in pounds])

Note: The individual with the lowest score wins.