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Instructional Strategies to Promote Student Strategic Thinking when Using SolidWorks

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ABSTRACT

Reflective of current trends in industry, engineering design professionals are expected to have knowledge of 3D modeling software. Responding to this need, engineering curricula seek to effectively prepare students for the workforce by requiring instruction in the use of 3D parametric solid modeling. Recent literature contains many examples that learning this type of software involves three types of knowledge: declarative command knowledge of the software, specific procedural command knowledge of the software, and most importantly for engineering design students, strategic knowledge of the software. Engineering design faculty, to be successful, should seek to implement teaching strategies and instructional practices that promote strategic thinking. However, current assessment of student success is often based on the inspection of the product of the modeling effort rather than the strategic thinking of the student during the construction process. This paper considers the impact of three instructional strategies on first year engineering design students' strategic thinking when using a 3D parametric modeling software package. Findings appear to suggest that 1) expertly modeling the design construction process may improve student confidence related to using CAD software, but does not impact student ability or proficiency with the software; 2) object construction is more effective at supporting the development of declarative command knowledge related to CAD software than engaging with and completing software tutorials; 3) Engaging with and completing the software tutorials supports the development of procedural command knowledge more effectively than constructing a design object and; 4) constructing a design object supports the development of strategic use of the software more effectively than expertly guided modeled design processes.

Keywords: Design, 3D modeling, instructional strategies

INTRODUCTION

This investigation seeks to explore the impact of three different instructional strategies used to teach CAD software to first year engineering design students and the impact of these strategies on student understanding and mastery of the 3D parametric solid modeling package as evidenced by their ability to plan and create effective and efficient design concepts. Specifically, we wanted to know if variations in instructional strategies would impact 1) students' ability to correctly identify the strategic steps needed to construct an assigned object, 2) how students plan and describe the strategic steps needed to construct an object, and 3) how efficiently and effectively students were able to execute the strategic steps needed to construct an object.

Engineers are problem solvers. As applied practitioners, they are charged with designing and developing solutions that take into account specific needs, constraints, and circumstances. As Mourtos [1] notes, "design is at the heart of engineering practice" and "many engineering experts consider design as being synonymous with engineering". Simon [2] emphasizes this thought and argues that design has been identified as the distinguishing mark of the engineering profession. Dym [3] extends this idea to describe design as a representation, "of both the artifact being designed and … the process by which the design is complete." This two fold process is detailed in the following excerpt from ABET I.C.3.d.(3)(c). 2000-2001: "Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective." How this definition impacts engineering curriculum is seen in the following ABET statement: "The engineering design component of a curriculum must include most of the following features: development of student creativity, use of open-ended problems, development and use of modern design theory and methodology, formulation of design problem statements and specifications, consideration of alternative solutions, feasibility considerations, production processes, concurrent engineering design, and detailed system descriptions [4]."

Solutions, then, need to be detailed and documented, ideas need to be modeled, tested, and shared. 3D parametric solid modeling tools allow users to create, share, visualize, test, and annotate digitized models of proposed solutions as real physical objects. "Computer-aided design is an iterative process that converts a designer's intentional model of functional requirements into an extensional computer representation of the final product." [5] Knowledge of, and proficiency with, 3D parametric solid modeling software is essential for design engineers in the workplace.

Dym [3] articulates the duality of what is meant by engineering design, how it can be discussed both for designed artifacts and for the process of design. Effective preparation of engineering students begins then with attention to developing engineering design skills that support this process of engineering design. The competencies that are assumed within the multi-faceted engineering design process, outlined by Ertas and Jones [6], include recognition of a need, conceptualization, feasibility assessment, establishment of design requirements, preliminary design, detailed design, production planning and tool design, and, finally, production. To frame and scaffold student thinking, students are guided through the overarching steps of the design process. The process can be, according to Corbett et al. [7] condensed into four steps. These include: problem formulation, solution generation, solution analysis, and solution evaluation. Each of these large steps includes their own series of sub-steps. Engineers need to 1) identify and define the problem; 2) collect information; 3) develop/consider multiple solutions; 4) analyze, evaluate, and select solutions; 5) test and implement solutions; 6) and communicate the design solution. These steps are iterative in nature and become the plan that frames and supports product development. Mourtos [1] has noted that, in addition to the iterative process that requires the successful designer to move freely back and forth between the analytical evaluation of information and the creative synthesis necessary to create something new, students must also be able to visualize their thoughts, model how this new idea might take shape and test and share their ideas. Three dimensional parametric solid modeling tools use computer technology predicated on scientific and mathematical principles to allow the user to create, visualize, share, test, and annotate digitized models of proposed solutions as real physical objects. Knowledge of, and proficiency with, 3D parametric solid modeling software is essential for many design engineers in the workplace. Thus, instruction in the use of this software is a key component of engineering education.

EDUCATIONAL CONTEXT

As educators, we are charged with preparing students for the workplace – but what does that entail in terms of 3D parametric solid modeling? Branoff and Hartman [8] consider that very question from the standpoint of the needs and educational objectives of three groups of stakeholders who utilize constraint-based CAD software in the workplace. They concluded that Engineering

Design Graphics educators need to consider that the current trend in industry is to look for individuals who are able to use 3D parametric CAD software to move information through the design process, collaborate with project teams, and manipulate, interpret, edit, and design products utilizing these programs. However, Branoff, Hartman, and Wiebe [9] explain that expectations and necessary skillsets vary for different stakeholder groups, which include technicians, technologists and engineers. They go on to suggest that a three-tiered model of curricular instruction for 3D CAD is necessary since the topics covered for each stakeholder group are iterative. Technicians need to have proficient command knowledge of the software to be able to execute the specific operations and tasks necessary for creating technical drawings. Technologists, however, require mastery of the procedural knowledge necessary to be able to use the 3D software to translate and operationalize the information in the technical drawings. [Design] Engineers need to be able to analyze, evaluate, and innovate using the 3D software. An engineer's knowledge and proficiency would emphasize strategic knowledge related to a modeling program. An engineer needs to have the technician's ability to generate technical drawings that portray the specified component as well as the technologist's ability to utilize mathematical and geometric principles necessary to translate the idea or concept into a workable model using the software. But engineers also need to develop a skillset that includes the ability to conceptualize and plan using the software – which focuses on expertise related to strategic knowledge.

Expertise and dexterity with the software, then, is different for each stakeholder group – and is reflective of the type of knowledge the user must possess in order to be successful in utilizing the software program. Effective preparation of students for the workplace needs to consider the overarching needs of these stakeholders if it is to be successful in teaching students 3D parametric solid modeling.

Developing expertise with 3D parametric CAD software is central to engineering design because it is the tool that is used to translate this fluidity of process. Supporting students' use of the software's tools, commands, and processes effectively is vital for instruction to be successful. As instructors we need to be able to support the development of design expertise in students. That is, we need to teach students to think strategically when using the software. Chester [10] suggests that development of expertise using CAD requires three types of knowledge. These are declarative command knowledge, specific procedural command knowledge, and strategic CAD knowledge.

Declarative command knowledge is, as Chester describes, knowledge about the commands or algorithms available within the software, and would be stressed when teaching technicians to create technical drawings. Specific procedural command knowledge, he notes, is information or knowledge that allows the user to execute various commands such as copy objects, mirror lines, or extrude an item to create a solid and would be stressed when teaching technologists to translate the information in a drawing. Strategic CAD knowledge is the ability to recognize that there are several ways to do a specific task, and understand that design choices made as the model is developed have implications for ease of editing and design changes later in the design flow.

It is this strategic CAD knowledge, the ability to choose between alternate problem solving methods, anticipate and predict consequences, and evaluate procedures, that is the learning outcome sought when teaching engineers and engineering design. Engineering students need to learn *what* [declarative command knowledge] and *how* [procedural command knowledge] as well as *when* and *why* [strategic knowledge]. The ability to be aware of and manage one's own executive thinking [*strategically think* with the software], implies planning, monitoring, evaluating, and revising. Thinking strategically, according to Heracleous [11], "comes down to the ability [of] … being able to see both the big picture and the operational implications." Liedtka [12] explains that strategic thinking involves "thinking and acting within a certain set of assumptions and potential alternatives as well as challenging existing assumptions and action alternatives, potentially leading to … more appropriate ones." This awareness and understanding of one's cognitive processes is known as metacognition.

Strategic thinking with CAD software assumes the ability to recognize the steps one needs to take to render a specific object. A strategic step can be defined as the conceptualization, and subsequent construction, of a component, part, shape, or object, or the performance of a series of procedural commands, which results in the rendering of a significant, distinct portion of the end product being modeled. Deconstructing this definition allows us to identify the three criteria that underpin this statement.

First, the ability to identify and list the strategic steps necessary to model an object is reflective of the user's ability to move between the abstract design knowledge and concrete/applied design practice in terms of replicating that object using the CAD software package. It requires the user be able to 'see' the structures that comprise the object, and know the CAD commands that allow the user to generate those structures and execute the design. This ability to deconstruct the object into component parts is reflective of the user's plan or strategy to model that object.

Second, the ability to execute the design is reflective of the user's ability to translate the abstract plan or model piece into a series of command procedures that generate the object.

Third, the chosen command procedures, and the way in which the user sequences those command procedures, is reflective of efficient and effective use of the software.

Assessment of student success should consider how well students progress towards each of these three criteria. In other words, we need to be able to measure student thinking related to the skills that have been iterated above. Bloom's taxonomy provides a categorization structure that classifies the type of thinking necessary for students to successfully demonstrate learned skills. Bloom's taxonomy, then, provides a descriptive yardstick to measure the type of cognition assumed

Bloom's Taxonomy Description	First Year Engineering Design Outcomes and Skillsets
Remembering: Retrieving, recognizing, and recalling relevant knowledge from long-term memory.	Students need to be able to *recall* the commands necessary to execute various steps within the program, *recognize*, and *retrieve* the appropriate command for individual actions.
Understanding: Constructing meaning from oral, written, and graphic messages through interpreting, exemplifying, classifying, summarizing, inferring, comparing, and explaining.	Students need to be able to *describe* and *communicate* the various steps needed to execute the identified actions and processes within the program.
Applying: Carrying out or using a procedure through executing, or implementing.	Students need to carry out/execute the steps they have learned – i.e. apply learned knowledge
Analyzing: Breaking material into constituent parts, determining how the parts relate to one another and to an overall structure or purpose through differentiating, organizing, and attributing.	Students need to be able to *'see' the structures that comprise the object* in order to replicate the object. Students need to *formulate a plan* that sequences the modeling needed *to replicate the object*.
Evaluating: Making judgments based on criteria and standards through checking and critiquing.	Students need to *model the plan*. Actual modeling allows the student *check the sequence of command procedures*, confirming or critiquing effective and efficient use of the software.
Creating: Putting elements together to form a coherent or functional whole; reorganizing elements into a new pattern or structure through generating, planning, or producing.	Students generate a *final product* that is the end product of the design assignment/process.

Table 1. Pairing Bloom's Taxonomy as described by Anderson & Krathwohl [13] to First Year Skillset.

in various skillsets of learning. The matrix that is Table 1 pairs Bloom's categorical descriptions of thinking with first year engineering design skills and outcomes. These first year engineering design skills and outcomes are the evidence of student ability to think strategically with the software. It is relatively easy to observe the relationships between Bloom's taxonomy and the skillsets needed by first year engineering students engaged in developing their abilities with 3D parametric CAD software. Command knowledge pairs with remembering/understanding. Procedural knowledge pairs with applying. Strategic knowledge pairs with analyzing/evaluating/creating.

Teaching which seeks to enhance student thinking is of critical importance. Assessing the effectiveness of various teaching strategies for targeted learning objectives, then, is a logical extension of this effort. The goal of this investigation is to explore if any one instructional strategy better facilitates student ability to think strategically with the software.

INSTRUCTIONAL STRATEGIES

The methodologies used to teach CAD included tutorials, hands-on practice, and instructor-led instruction. However, evaluation of the success of such solid modeling instruction is often based on the inspection of the 'product' of the modeling effort rather than the student decision-making process that occurs *during* the modeling effort. In other words, student strategic thinking, or strategic application/use of the software is often **not** assessed. However, if instruction is intended to promote strategic thinking related to software use, then assessment of such instruction to address strategic knowledge is critical. This assessment, as alluded to earlier, needs to measure how well students are able to: 1) identify the steps or commands needed to create a design object, 2) execute those commands as command processes or procedures, and 3) sequence those processes and procedures based on a set of design options and constraints.

The matrix that is Table 2 extends the parallel made previously between the types of knowledge that underpins First Year Outcomes to show how each of the three instructional strategies operationalizes support for student learning. It is important to note that while *each* instructional strategy can successfully address and support the type of learning required for the skills required of first year engineering students – the way the strategy manifests support for student learning differs. Table 2 captures this as a matrix across each condition during the instructional cycle.

As noted earlier, we are interested in discovering what instructional strategies might best support students in developing the ability to think strategically with the software. The goal of this study was to determine if the type of instructional strategy used to teach SolidWorks to first year engineering design students impacted student strategic thinking, and hence student ability to plan and create effective and efficient design concepts. In terms of instructional practice, we desired to be able to discern the impact of instructional methods on student's ability to:

1. Identify the strategic steps required in the construction of solid models. The ability to identify and list the strategic steps necessary to model an object is reflective of the user's ability to move between the abstract design knowledge and concrete/applied design practice in terms of replicating that object using the CAD software package. It requires the user be able to 'see' the structures that comprise the object, and know the CAD commands that allow the user to generate those structures and execute the design. This ability to deconstruct the object into component parts is reflective of the user's plan or strategy to model that object.
2. Effectively 'chunk' these strategic steps into procedures mimicking expert thinking. The ability to execute the design is reflective of the user's ability to translate the abstract plan or model piece into a series of command procedures that generate the object.
3. Select the most efficient path [plan] for appropriate construction of solid models. The chosen command procedures, and the way in which the user sequences those command procedures, are reflective of efficient and effective use of the software.

To facilitate this assessment, a rubric was developed to measure the ability of students to think strategically (i.e. identify the strategic steps required in the construction of solid models, effectively

Knowledge Type‖Outcome	Tutorial Focused Instruction as Instructional Strategy	Object Focused Instruction as Instructional Strategy	Instructor Led Instruction as Instructional Strategy
If students need to *recall, remember, recognize,* and *retrieve* the appropriate command for individual actions; then *strategies* should provide text information and simple testing.	Content, presented as text to be read; tutorial activities have students replicate actions then provide opportunities for students create a sample object as part of the tutorial. HW is assigned as simple test.	Content, presented as text to be read tutorial activities have students replicate actions then provide opportunities for students create a sample object as part of the tutorial. Object development is required before end of class. HW is assigned as simple test.	Content, presented as text but also explained by the instructor; tutorial activities have students replicate actions guided by the instructor; students create sample object as part of tutorial. HW is assigned as simple test.
If students need to be able to *describe, explain and communicate* the various steps needed to execute the identified actions and processes within the program; then *strategies* should include opportunities for restatement and, paraphrasing.	Students, through tutorial help functions, are able to read detailed explanations of commands; are presented with various options for generating objects; and have the ability to ask the instructor or fellow students questions during lab. Homework acts as 'restatement' opportunity	Students, through tutorial help functions, are able to read detailed explanations of commands; are presented with various options for generating objects; and have the ability to ask the instructor or fellow students questions during lab. Homework acts as 'restatement' opportunity	Students are guided, through tutorial help functions, are able to read detailed explanations of commands; are presented with various options for generating objects; and have the ability to ask the instructor or fellow students questions during lab. Homework acts as 'restatement' opportunity
If students need to carry out and execute the steps they have learned i.e. *apply* learned knowledge; then *strategies* should include opportunities for practice and repetition.	Student practice is afforded within the tutorials as they walk through step by step instructions and activities of the tutorial. Skills are practiced/replicated as engagement to complete the tutorial and HW assignments.	Student practice is afforded within the tutorials as they walk through step by step instructions and activities of the tutorial. Skills are practiced and replicated as engagement to complete the tutorial, the end of session object, and HW assignments.	Practice is afforded, guided by the instructor, within the tutorials as they walk through step by step instructions and activities of the tutorial. Skills are practiced/replicated as engagement to complete the tutorial and HW assignments.
If students need to be able to *'see' the structures that comprise the object* in order to *deconstruct* and replicate the object and students need to *analyze* the sequences of modeling needed to replicate the object; then strategies should include 'component' and 'whole' view illustrations and examples, chunk information into parts, and provide opportunities to connect information.	Tutorials walk students through the construction process of an object so students can see how the object is constructed – illustrating component and whole views, previewing how the model is sequenced and the object is constructed. Opportunities to connect concepts are provided through tutorials, and homework.	Tutorials walk students through the construction process of an object so students can see how the object is constructed – illustrating component and whole views, previewing how the model is sequenced and the object is constructed. Opportunities to connect concepts are provided through tutorials, the end of session object, and homework.	Tutorials walk students through the construction process of an object so students can see how the object is constructed – illustrating component and whole views, previewing how the model is sequenced and the object is constructed. Opportunities to connect concepts are provided through tutorials and homework.
If students need to *model the plan* and actual modeling allows the student to *check the sequence of command procedures*, confirming effective/efficient use of the software; then strategies should include examples/ opportunities for executing a plan.	Tutorials provide opportunities for students to test assumptions, self-monitor progress, and extend prior experience and practice to homework. Project work and homework affords opportunity to re-formulate learned concepts in new ways.	Tutorials provide opportunities for students to test assumptions, self-monitor progress, and engage in an immediate activity to extend prior experience and practice to homework. Project work and homework affords opportunity to re-formulate learned concepts in new ways.	Tutorials provide opportunities for students to test assumptions, self-monitor progress, get instructor feedback on progress, and extend prior experience and practice to homework. Project work and homework affords opportunity to re-formulate learned concepts in new ways.

Table 2. Matrix Pairing Knowledge 'Types' Across Instructional Strategies. (continued)

Knowledge Type||Outcome	Tutorial Focused Instruction as Instructional Strategy	Object Focused Instruction as Instructional Strategy	Instructor Led Instruction as Instructional Strategy
If students need to generate a *final product* that is the end product of the design assignment/process; then strategies should include opportunities for practice, solicit/encourage reflection on performance, and allow for revision.	Tutorials *are* practice for the final product providing work on compound parts. Homework assignment provides interim assessment and feedback. Revision is afforded through work on homework and project object development and final project. Reflection opportunities are embedded as part of homework and project process.	Tutorials *are* practice for the final product providing work on compound parts. Homework assignment provides interim assessment and feedback. Revision is afforded through work on homework and project object development, end of session object, and final project. Reflection opportunities are embedded as part of the end of session object, homework, and project process.	Tutorials *are* practice for the final product providing work on compound parts. Homework assignment provides interim assessment and feedback. Revision is afforded through work on object development and final project. Reflection opportunities are presented by the instructor and are embedded as part of the homework and project process.

Table 2. (Continued)

'chunk' these strategic steps together and select the most efficient pathways for appropriate construction of solid models). This rubric is detailed in the instruments section of this paper.

Each instructional strategy occurred during allotted class time. Only the strategies used to communicate the content during class time was varied. Allotted lab time for each group included instruction and working through the tutorials. If students in any of the conditions completed the tutorials (and the object in the Object-focused group) they could begin work on the homework assignment.

CONTEXT OF STUDY

The study was undertaken in three sections of a freshman engineering design course at a large, mid-Atlantic public university. Across the University's College of Engineering, approximately 640 students are enrolled in the course each semester. Overall, approximately 20 sections of 32 students are offered each semester. Each design section is staffed by one instructor and 1 to 2 lab assistants who facilitate and support students' learning of the software.

The course introduces students to the engineering design process. Students engage in design activities requiring them to apply mathematical and science-based problem-solving to generate problem solutions. Students design and evaluate their design ideas and construct conceptual prototypes. Two design projects are assigned during the semester. This design-driven curriculum emphasizes skills such as teamwork, communication (graphical, oral, and written), and sufficient proficiency with computer-aided drafting and analysis tools.

The goal of the course is not to make the student an expert in the use of the software per se; but rather, to enable the student to be sufficiently proficient in a 3D parametric solid modeling CAD software in order to effectively communicate design solutions for the two design projects undertaken in the course. The vast majority of faculty who teach first year design choose to use the 3D CAD package SolidWorks.

In alignment with ABET Engineering Criteria Program Outcomes 3a through 3k, the course outcomes are concerned with focusing on these objectives while incorporating solid modeling instruction. As a result, this course incorporates graphical, oral, and written communication skills, specifically an ability to communicate effectively using SolidWorks. Given this focus, the course operationalizes these outcomes in the following objective:

"Given access to professional quality solid modeling software, students will engage in project-related assignments that will facilitate and support student ability to:

a. recognize where and when procedures such as extrude, loft, revolve, part, assembly, and drawing are useful and
b. develop project concept drawings and design documentation that includes procedures such as: extrude, loft, revolve, part, assembly, and drawing."

Given the large numbers of students, over 600 a semester, it would benefit both students and faculty if 'best practices' or successful strategies could be identified and implemented. The driving question behind this research is: Which instructional methods result in discernible differences in student's strategic thinking when learning SolidWorks? In terms of this research, we are specifically asking which instructional methods result in students having a greater ability to 1) identify CAD commands; 2) organize those commands into a series of command procedures; and 3) sequence those command procedures [i.e. strategically think] to communicate a design concept using SolidWorks.

We implemented three instructional conditions that focus on each of the instructional methods currently used by faculty to teach SolidWorks in the course. These instructional strategies were used to initiate lab or class sessions, in preparation for homework assignments, to teach the first year design course. Each strategy was executed during one class period. Consistent across all groups is the homework assignment that requires students to apply the content being learned as evidence of competency. Only the initial instruction used to convey the CAD tutorial content was varied. Class sessions were opportunities for students to receive instruction and to engage in practice. Homework assignments were applied practice for concepts learned during the tutorials. We outline next the instructional strategies and their operationalization for this investigation.

Tutorial Focused Instruction

This strategy involved providing students brief instruction of the software commands *prior* to using the SolidWorks tutorials as lab activity to generate the tutorial object. Class practice is self-directed and tutorial driven. The homework assignment provides assessment for the activity. This method allowed us to establish a baseline to examine how the impact of the tutorials coupled with practice on assigned objects in the tutorials, impacted the ability of students to think 'strategically' with the software.

Instructor Led Instruction

This strategy involved providing students direct, detailed, step-by-step instruction, walking students through the commands and procedures included in the software tutorials *prior* to using the SolidWorks tutorials as lab activity to generate the tutorial object. Class practice is instructor-directed and tutorial driven. The homework assignment provides assessment for the activity. This method allowed us to isolate and examine how the impact of having prerequisite familiarity with the tutorial commands and procedures coupled with practice on assigned objects in the tutorials, impacted the ability of students to think 'strategically' with the software.

Object Focused Instruction

This strategy involved providing students brief instruction of the software commands *prior* to using the tutorials as lab activity practice to generate the tutorial object, followed by assigning an *end of lab session deliverable*. Class practice is self-directed and object driven. The homework assignment provides assessment for the activity. This method allowed us to isolate and discern how generating a post tutorial object coupled with student practice on assigned objects in the tutorials impacted the ability of students to think strategically with the software. Table 3 juxtaposes the three instructional strategies and how they play out in the instructional setting.

RESEARCH DESIGN

Participants

Students enrolled in three of twenty sections of a freshman engineering design course served as participants in the study. A total of 89 students participated in the study. Twenty-five students were enrolled in the first section (the Tutorial Focused Instruction group), twenty-nine students were enrolled in the second section (the Instructor Led Instruction group), and thirty-five students were

Tutorial Focused Instruction	Instructor Led Instruction	Object Focused Instruction
Students get brief explanation of what to expect and how to access/execute commands in the CAD tutorial instruction and work through CAD tutorials relative to the assigned hw object	Instructor provides detailed explanation as students are 'walked through' and work to complete CAD tutorials relative to the assigned hw object.	Students get brief explanation of what to expect and to access/execute commands in the CAD tutorials instruction and work through CAD tutorials relative to the assigned hw object
– students complete the tutorial object on their own	– students complete the tutorial object along w/instructor	– students complete the tutorial object on their own
		– students are given an object task to complete
– students can begin working on the homework [object] assignment once the tutorial is completed	– students can begin working on the homework [object] assignment once the tutorial is completed	– students can begin working on the homework [object] assignment once the tutorial and task are completed
end of lab session	*end of lab session*	*end of lab session*
– homework assignment [object] is evidence of partial skill competency needed to create the final project object	– homework assignment [object] is evidence of partial skill competency needed to create the final project object	– homework assignment [object] is evidence of partial skill competency needed to create final project object
– completed homework assignment is turned in for feedback and grading	– completed homework assignment is turned in for feedback and grading	– completed homework assignment is turned in for feedback and grading

Table 3. Variation of strategies during instructional cycle.

enrolled in the third section (Object Focused Instruction group). All three sections were taught by the same instructor. The gender distributions for course by section, has been captured in Table 4 below.

Instruction and Data Collection Procedures

All three sections included SolidWorks instruction that was divided into three large instructional modules. Each instructional module consisted of 4 class sessions [3 instructional classes and 1 design activity class], with each module extending over a 4-week period (one two-hour meeting time per week). Four data collection points were established: 1) the start of the semester; 2) the beginning & end of the first instructional module design activity; 3) the beginning & end of the second instructional module design activity; and 4) the beginning & end of the third instructional module

	Male	Female	No Answer	Total
Tutorials Focused Group	21	4	2	27
Instructor Led Instruction Group	23	6	–	29
Object Focused Instruction Group	33	2	–	35

Table 4. Participant demographics.

1X Data Collection				**Instructional Cycle**			
Initial Data Collection	Week 1 Class Session	Week 2 Class Session	Week 3 Class Session	*Pre Design Activity Data Collection*	Week 4 Design Activity	*Post Design Activity Data Collection*	Homework Assignment

Table 5. Timeline of instruction and data collection.

design activity. A different instructional strategy was consistently employed in each section over the course of the semester. During the instructional sessions, students were introduced to a specific set of 3D modeling features and operations pertinent to learning SolidWorks at that stage of the course. Each module focused on building the skills necessary to be successful in completing specific modeling tasks. At the end of each instructional module, an assignment was given that was due the following week. This is depicted in Table 5.

Prior to implementing the instructional strategy, the instructor began the Design Activity session in each section by providing a simple introduction on the day's lesson assignment. After the instructor's introduction, students in the Tutorial Focused Instruction group were asked to complete instructional tutorials and assignment offered in the SolidWorks software package to learn the CAD process and then could begin work on the homework assignment. Students in the Instructor Led Instruction group received detailed, step-by-step instructions from the instructor on how to accomplish the tasks for the assignment and were instructed to complete the same instructional tutorials and assignment as students in the Tutorial Focused Instruction group then could begin work on the homework assignment. Students in the Object Focused Instruction Group completed the same instructional tutorials and assignment as the other groups, but were required to complete a simple object incorporating the topics included in that day's task before beginning the homework assignment. It should be noted that not all students in the Object Focused Instruction group were able to complete the tutorials and tutorial assignment during class time and completed the activity outside of class. Table 6 illustrates the instructional flow for the various strategies.

In order to assess the effectiveness of each instructional condition, data was collected at four points. A 'Previous Experience Survey' was administered at the beginning of the semester to ensure that there were no underlying differences in experience with CAD software among the sections. Data was also collected during each design activity class session which closed each instructional module. During each of the three design activity class sessions students engaged in: a) a 'Pre Design Activity Survey' at the beginning of the class session, b) the actual 'Design Activity Exercise,' and, upon submission of the design activity c) the 'Post-Design Activity Survey'. An overview of this process is displayed in Table 7.

Class Session						
Group	**Concept Introduction**	**Session Activity/Description**			**Students Work to Complete Homework**	**HW Due *Following Week***
Tutorial Focused Instruction	Instructor Introduction	Complete CAD Tutorial and Tutorial Assignment		Could Begin HW Assignment	Work to Complete HW	Homework Due
Instructor Led Instruction	Instructor Introduction	Instructor provides detailed step by step instruction of CAD tutorials & assignment	Complete CAD Tutorial & Tutorial Assignment	Could Begin HW Assignment	Work to Complete HW	Homework Due
Object Focused Instruction	Instructor Introduction	Complete CAD Tutorial and Tutorial Assignment	Create Simple Object	Could Begin HW Assignment	Work to Complete HW	Homework Due

Table 6. Instructional flow of strategies.

Each design activity focused on developing a specific object in SolidWorks. This was undertaken in a three-step process. First, prior knowledge and understanding of the software relevant to the specific object was measured prior to each design activity using the Pre Design Activity Survey. This survey provided students a Design Activity Exercise Object and asked students to list the strategic steps they would take to construct a model of that object using the CAD software. Second, students then engaged in generating the session's Design Activity Exercise Object, recording all steps in the process in great detail, using the software. Upon submission of this Design Activity, students were presented with the Post-Design Activity Survey, which measured post knowledge and understanding of the software. The Post Design Activity Survey repeated the same questions as the Pre Design Activity Survey, requesting the student identify the strategic steps required to construct the object. Further description of all instruments follows.

Instruments

Previous Experience: The Previous Experience Survey, developed by the researchers, was administered to all three sections at the beginning of the semester. The intent of the Previous Experience

Design Activity Class Session			
Previous Experience Survey	PRE Design Activity Survey Phase 1	Design Activity Exercise Phase 2	POST Design Activity Survey Phase 3

Table 7. Overview of the design activity process.

Survey was to determine whether or not students in different sections had had similar previous experience with CAD software. Students were asked to indicate their experience with various software packages and to indicate their confidence in their ability to construct an object using the software package SolidWorks. The questions related to Previous CAD software experience are captured in Appendix A. All responses were collected online using an online survey tool called Qualtrics.

Pre Design Activity Survey: [Phase 1] This survey sought to measure students' knowledge and understanding of the CAD software package prior to engaging in the design activity. The survey included an example object along with an activity object. The example design object included a description and list of the strategic steps used to explain how the object was created. This demonstrated for students the level of detail sought for listing and describing the strategic steps they would take to construct the activity object they were given. For the Pre Design Activity Survey, students were asked to record and describe the strategic steps they would take to generate the activity object.

The *actual* design activity objects for each instance can be seen in Appendix B. Students were ready to begin the Design Activity [Phase 2], once responses to the Pre Design Activity Survey were submitted. Each of the design activities was constructed to contain all elements covered in each of the three previous SolidWorks instructional sessions.

Post Design Activity Survey: [Phase 3] The Post Design Activity Survey sought to measure student knowledge and understanding of the CAD software package after engaging in the design activity by again presenting students with the day's design object. As in the Pre Design Activity Survey, students were presented an image of the day's object, and were asked to list and submit the strategic steps necessary to recreate the object. The Post Design Activity Survey also contained six additional questions to collect information on tutorial use, student perceptions related to preparedness for the design activities, and student perceptions regarding the instruction they received related to the SolidWorks software. The questions common to both the Pre and Post Design Survey and the Post Design Survey items can be found in Appendix C. A progression of the data collection during the Design Activity Session is described in Table 8.

Phase 1 Pre Activity Survey	Phase 2 Design Activity	Phase 3 Post Activity Survey
– First, an example is given depicting an object and the strategic steps needed to create that object – Students are then presented with a design object and asked to list the strategic steps they would use to create the object	– Using the presented design object, students engage in design activity to actually create the design object – Students take notes to detail their actions as they progress through the exercise	– Student have completed the design activity, and are asked *in retrospect* to list the strategic steps they would now take to create the object

Table 8. Design activity session data collection process.

Confidence: To measure confidence in their ability to complete the assigned task, a "confidence" question was asked in the Previous Experience Survey and repeated in each of the three Pre Design Activity Surveys and Post Design Activity Surveys. Students were asked to rate their current confidence in their ability to construct an object using the CAD software on a 0 to 10 likert-type scale. Anchors for the scale were: '0'-'Not At All Confident' and '10'-'Highly Confident.'

Use of a 10-point likert-type scale has the same psychometric properties as the more popular alternative 5 point scale. In their study for optimal number of alternatives for likert-type items, Matell and Jacoby [14] concluded that reliability and validity are unrelated to the number of alternatives. Similarly, Wakita, Ueshima, and Noguchi [15] found that the reliability estimate is independent of the number of options. In other words, utilization of 10-point scale items in the current study should not have impact on the student's response, and subsequently, the validity and reliability of the findings.

Scoring Rubric: A rubric for each design activity object predicated on the criteria that underpin and define strategic thinking as it applies to using 3D parametric modeling software was generated. This approach allowed the assessment to be object-specific since the 'number' of strategic steps, level of strategic steps, and set path for each object could be assigned for each object. In other words, the rubric could adjust for the number of strategic steps necessary to generate each object, how the steps should be grouped for each specific object, and possible paths for each object. Hence, it was possible to create a consistent yet object specific set of criteria that could be applied across multiple objects.

The rubric was used to score student responses to the request to "list the strategic steps needed for [each of] the following design object[s]. This rubric was also applied to score responses on both the Pre Design Activity Survey and the Post Design Activity Survey. Three criteria were formulated into each design object rubric that can be mapped back to the type of thinking that supports the development of CAD expertise: 1) declarative command knowledge, 2) specific procedural command knowledge, and 3) strategic CAD knowledge. The rubric then allowed us to assess with consistency student ability to strategically think using the software across the development of multiple objects. The first criterion was the presence of strategic steps, or the ability to recognize, identify, and state the series of actions necessary to create the assigned object, which is reflective of declarative command knowledge of the software. The second criterion was listing the steps at the correct level, or the ability to group or chunk the listed actions into sets of steps or procedures, which is reflective of procedural command knowledge of the software. The third criterion was the extent to which the set path was efficient and effective, or the order in which the student chooses to execute the steps to carry out their plan or design process, which is reflective of strategic knowledge and understanding of the CAD software.

	LOWEST Score			HIGHEST Score
	1	2	3	4
DIMENSION #1: *PRESENCE* of Strategic Steps	**0**	**1-2**	**3-5**	**6-7**
1.1 Part	0	1	2	3
1.2 Assembly	0	1	2	3-4
DIMENSION #2: Steps listed were at the correct *LEVEL*	**20 or more**	**14-19**	**8-13**	**0-7**
2.1 Part	10 or more	7-9	4-6	0-3
2.2 Assembly	10 or more	7-9	4-6	0-3
DIMENSION #3: Set *PATH* was efficient and effective	**0**	**1-2**	**3-5**	**6**
3.1 Part	0	1	2	3
3.3 Assembly	0	1	2	3

Figure 1. Example of Design Rubric – Design Activity 1.

The rubric for Design Activity 1 has been deconstructed in Figure 1. The black row labeled as "Lowest Score – Highest Score" indicates the rubric scoring levels for each dimension or rubric category. Students can score a 1, 2, 3, or 4 for each dimension category with 4 being the highest score a student can earn. The dark gray row labeled "Dimension 1" indicates the overall correctly identified number of strategic steps that are present in the listed actions detailed by the learner when asked to list the strategic steps they would use to generate the pictured object. For example, if a total of '0' or no strategic steps can be identified in the student generated list the part [line 1.1] the user would receive a '0' for the presence of strategic steps for line 1.1/Presence of Strategic Steps/Part. If a total of '0' or no strategic steps can be identified in the student generated list for the assembly [line 1.2] the user would receive a '0' for the presence of strategic steps for line 1.2/ Presence of Strategic Steps/Assembly. Hence the user would earn a dimension #1 rubric score of '0' for the presence of strategic steps – i.e. (line 1.1 + line 1.2) = total presence of strategic steps SCORE for dimension #1. Likewise, if a total of '3' strategic steps can be identified in the student generated list to create the part and '3' or '4' strategic steps can be identified in the student generated list to create the assembly [depending on the chosen path] the student would earn a dimension #1 score of '6' or '7'. Similarly, if a user's list of actions identified '3' strategic steps for the part [line 1.1] and '2' strategic steps for the assembly [line 1.2] – a dimension 1 total of '5' for the Presence of Strategic Steps – the user would be awarded a dimension 1 score of '3'for the Presence of Strategic Steps.

This logic continues for dimension #2 which assess the granularity [how students grouped actions into procedures]; and again the logic repeats itself for dimension '3' which indicates if the path [or sequence of commands] listed is the most efficient.

A complete rubric score would be a summary of each dimension e.g. 3-1-3, 4-4-4, etc. Appendix D contains the rubrics for each of the design activities, followed by both a low-scoring and high-scoring student example that has been deconstructed.

To benchmark criteria for each of the assignment rubrics, the faculty member and six teaching assistants for the engineering design class were each given the objects for each design activity. Each individual was asked to list the strategic steps they would take to create the objects using the CAD software. Based on these responses, several criteria were compiled and used as benchmarks for scoring. Consensus among faculty and TA generated designs revealed how each level of each design activity would be manifest in each rubric, including the number of strategic steps, the level at which the strategic steps were grouped, and what the most effective and efficient way to sequence the commands needed to create the design object. Hence, correctly identifying the strategic steps needed to create the design object was representative of declarative command knowledge needed to create the parts that comprised the object, row 1 of the rubric. Listing the steps at the correct level, row 2 of the rubric, was evidence of procedural command knowledge, demonstrating and reflecting student knowledge and understanding of how individual commands are grouped as part of a procedure. How procedures [strategic steps] need to be identified and sequenced to generate the object being designed is seen in row 3 of each rubric. This row of the rubric, scores student ability to sequence command procedures effectively. Students who listed and described their design process in more 'steps' [i.e. detailing lower level command steps] were less able to differentiate between the larger procedural steps needed to generate an object and the individual command steps that comprise each procedure. In other words, the higher the number of steps detailed by the student – the lower their rubric score. These benchmarks were then translated into the rubric grid and applied to individual student responses to the question "list the strategic steps" in the Pre Design Activity Survey and the Post Design Activity as a way to assess student's strategic knowledge of the software. This benchmarking process allowed us to use the rubric as a scoring mechanism, permitting us to create a consistent scale between design tasks so that equitable comparisons could be made across tasks. These design activity rubrics and objects are shown in Appendix D.

Actual scoring of student submissions was done by the instructor and the TA for the course. For each pre and post design activity a random sample of 20 student submissions was selected. The instructor and the TA each graded these 20 submissions applying the rubric. After each completed grading the sample, the TA and instructor compared and reviewed their results. Comparison and discussion between the instructor and the TA found their respective application of the rubric and subsequent grading to be comparable.

DATA ANALYSIS

Previous Experience Survey

To determine whether the class sections had differences in previous experience with drafting and design software, analysis of variance (ANOVA) was used to compare sections on items from this scale. Due to violations in homogeneity of variance, Welch's test was used to compare sections for – Prior CAD experience; Prior experience with SolidWorks; and Prior experience with Auto-CAD. Pairwise deletion was used for all analysis. ANOVA was also used to compare means for Student Confidence on the Previous Experience Survey.

Pre and Post Design Activity Surveys

To examine students' perceptions of each of the three conditions, student means on Confidence items in the Pre Design and Post-Design Activities were compared. Further analysis using Brown-Forsythe Robust tests of Equality of Means and Tukey's HSD for Post ANOVA Pairwise Comparison test was used to identify where the differences occurred.

To examine the central research questions regarding which instructional method results in enhanced strategic thinking, three subscale scores on the Pre and Post Design Activity Rubrics were compared: 1) the Presence of Strategic Steps, 2) the Level of Strategic Steps, and 3) the Path Efficiency and Effectiveness. The rubric subscale scores were totaled on each dimension across all three design/activities to derive a mean score for each dimension. ANOVA was used to compare means of the Pre Design Activity Rubric scores and the Post Design Activity scores across all three sections. A repeated measures ANOVA was used to determine if there were changes between the Pre Design Activity Rubric Scores and Post Design Activity Rubric Scores.

Six additional questions on the Post-Design Activity Survey provided information related to tutorial use, student preparedness for the design activities, student perceptions related to the instruction they received, and student frustration associated with learning the SolidWorks software. Comparisons for 2 of the rating scale items were examined using ANOVA. Frequencies of responses were compared for the remaining dichotomous items.

Students had the opportunity to provide free text responses to the final item as well as to provide comments or clarification to survey questions. Open responses and explanatory text remarks were analyzed similar to Strauss and Corbin's [16] comparative method technique. Comments and remarks were reviewed to identify key points or items identified by each participant response and coded accordingly. These points were then grouped by similarity or concept.

Groups of like concepts became a category. Reviewing the text in this manner generated the themes and trends in responses. However, since the intent of this investigation was not produce or generate 'theory,' but to meaningfully reduce and organize the data, a more selective approach, akin to Miles and Huberman's reduction process was used to isolate patterns [17]. Using the previously identified codes, matrices were generated to reflect points mentioned in student comments as well as the number of times the point was mentioned. These became the initial coding units. As responses were reviewed again, and matrices revised, the most prevalent elements were noted and revised. This led to a set of data that could be used to provide insight into student responses.

RESULTS

Previous Experience Survey

No statistically significant differences among the sections were found in Prior Drafting Experience, $F(2, 88) = .361$, $p > .05$; Prior Experience with Other 3D CAD Software, $F(2, 70) = .190$, $p > .05$; Prior CAD Experience $F(2, 51) = 2.511$, $p > .05$; Prior Experience w/SolidWorks, $F(2, 48) = .756$, $p > .05$; or Previous Experience with Auto-CAD, $F(2, 52) = 2.21$, $p > .05$. In addition, no differences were found overall for Total Prior Programming Experience between sections, $F(2, 51) = 1.23$, $p > .05$. These findings support that all students began the course with similar levels of experience with drafting and design software. The means are presented in the following table.

Student Confidence

No significant differences were found among conditions on students' confidence in their ability to construct an object using the software package on the Previous Experience Survey, $F(2, 81) = .811$, $p > .05$. These findings indicate that there were no differences found among the groups on the measure of confidence at the start of the course. The means and standard deviations for confidence are shown in the table that follows.

Pre/Post Design Activity Repeated Questions

Student Confidence A significant difference was found for Pre Design Activity 1 when comparing the means for Student Confidence across the three Pre Design Activity Surveys, $F(2, 78) = 3.23$,

	Drafting (SD)	CAD (SD)	SolidWorks (SD)	AutoCAD (SD)	Total (SD)
Instructor Led Instruction Group	1.83 (1.0)	1.76 (1.0)	1.21 (.4)	1.29 (.7)	6.0 (2.6)
Object Focused Instruction Group	1.63 (.97)	1.43 (.8)	1.11 (.4)	1.46 (8)	5.6 (2.6)
Tutorial Focused Instruction Group	1.85 (1.49)	2.19 (1.7)	1.33 (1.0)	2.00 (1.5)	7.3 (5.2)

Table 9. Previous experience means and standard deviation.

Confidence	Mean	Std. Deviation
Instructor Led Instruction Group	4.81	3.02
Object Focused Instruction Group	4.09	3.01
Tutorial Focused Instruction Group	5.08	3.23

Table 10. Means and standard deviation for confidence in previous experience survey.

$p < .05$. The Tukey post hoc test found the Instructor Led Instruction Group had significantly higher confidence scores than the Tutorials Only Group and the Instructor Focused Instruction Group. The table of means and standard deviations for Pre Design Activity 1 Confidence are presented in Table 11.

No significant differences in Student Confidence were found when comparing the means for Student Confidence across the three Post Design Activity Surveys.

Pre Design Activity Rubric Scores

ANOVA revealed statistically significant differences in overall Pre Design Activity rubric scores. Specifically, there was a significant difference in the overall Pre Design Activity scores between the Tutorial Focused Instruction Group and the Object Focused Instruction Group on the Presence of Strategic Steps, $F(2, 56) = 3.42$, $p < .05$ and on the Level of Strategic Steps, $F(2, 56) = 3.33$, $p < .05$. A table of means for these rubric scores can be found in Table 12 below.

The Tukey post-hoc test showed that, regarding the Presence of Strategic Steps [declarative command knowledge], students in the Object Focused Instruction Group had significantly higher mean scores on this dimension than the students in the Tutorials Focused Instruction Group. The means are presented in Table 13 below.

On the Level of Strategic Steps [procedural command knowledge]; the students in the Object focused Instruction Group had significantly lower mean scores than the students in Tutorial Focused

Pre Design Activity One	N	Mean	Std. Deviation
Instructor Led Instruction Group	24	7.00	2.13
Object focused Instruction Group	31	6.68	2.09
Tutorial Focused Instruction Group	26	5.58	2.10
Pre Activity One Overall	81	6.42	2.16

Table 11. Means and standard deviation for pre design activity 1 confidence.

Pre Design Activity Rubric Scores		Presence of Strategic Steps Mean (SD)	Level of Strategic Steps Mean (SD)	Path Efficiency/ Effectiveness Mean (SD)	Totals Mean (SD)
Instructor Led Instruction Group	Pre Design Activity 1 Score	3.08 (0.50)	3.67 (0.64)	2.63 (0.65)	9.38 (0.77)
	Pre Design Activity 2 Score	3.16 (0.47)	3.36 (0.70)	2.55 (0.51)	9.14 (0.89)
	Pre Design Activity 3 Score	3.21 (0.66)	3.83 (0.48)	2.14 (0.83)	9.27 (1.08)
Object Focused Instruction Group	Pre Design Activity 1 Score	3.48 (0.57)	3.29 (0.90)	3.40 (0.50)	10.20 (0.85)
	Pre Design Activity 2 Score	3.07 (0.54)	3.30 (0.61)	2.81 (0.40)	9.27 (0.72)
	Pre Design Activity 3 Score	3.22 (0.51)	3.89 (0.42)	2.43 (0.84)	9.61 (1.20)
Tutorial Focused Instruction Group	Pre Design Activity 1 Score	2.77 (0.71)	3.88 (0.33)	2.63 (0.77)	9.38 (1.06)
	Pre Design Activity 2 Score	3.09 (0.61)	3.55 (0.60)	2.78 (0.73)	9.50 (1.20)
	Pre Design Activity 3 Score	2.95 (0.79)	4.00 (0.00)	2.17 (0.86)	9.39 (1.09)

Table 12. Means for pre activity rubric scores.

Instruction Group. Relative to the Effectiveness and Efficiency of the Set Path [strategic knowledge], students in the Object Focused Instruction Group performed significantly better than the students in Instructor Led Instruction Group. These are captured in Table 14 below.

There was also a significant difference between the Instructor Led Instruction Group and Object Focused Instruction Group in the overall Pre Design Activity scores on the measure of Path Effectiveness and Efficiency, $F(2, 42) = 3.76$, $p < .05$. Students in the Object Focused Instruction Group had significantly higher mean scores than students in the Instructor Led Instruction Group. The table of means is presented as Table 15 below.

PRE Design Activity Scores		Mean (SD)
Tutorial Focused Instruction Group	Overall	8.83 (1.47)
Object Focused Instruction Group	Overall	9.74 (1.05)

Table 13. Presence of strategic steps for pre design activity scores.

PRE Design Activity Scores		Mean (SD)
Tutorial Focused Instruction Group	Overall	11.29 (.59)
Object Focused Instruction Group	Overall	10.41 (1.50)

Table 14. Level of strategic steps for pre design activity scores.

Post Design Activity Scores

No significant differences were found between the groups in overall Post Design Activity rubric scores on Presence of Strategic Steps, $F(2, 29) = .562$, $p > .05$; Level of Strategic Steps, $F(2, 19) = .056$, $p > .05$; or Path Effectiveness and Efficiency, $F(2, 12) = .103$, $p > .05$.

Comparing Pre and Post Design Activity Rubric Scores

A repeated measures ANOVA was conducted to compare the Pre Design Activity rubric scores and the Post Design Activity rubric scores to see if any interaction between the rubric scores and groups existed. None of the tests performed were significant. Within subjects test (Comparison of students performance across time) of the Pre and Post Design Activity rubric scores concluded that there are no significant differences for the Presence of Strategic Steps, $F(1, 13) = 3.97$, $P > .05$ (corrected for sphericity 3.075); The Level of Strategic Steps, $F(1, 13) = 1.29$, $P > .05$ (corrected for sphericity 1.068); and Path Effectiveness and Efficiency, $F(1, 13) = 1.47$, $P > .05$ (corrected for sphericity 1.57). Between subjects test (Comparisons made between the three instructional groups) found no significant differences in the Pre and Post Design Activity Rubric scores on the Presence of Strategic Steps $F(2, 13) = .41$, $P > .05$; the Level of Strategic Steps, $F(2, 13) = .62$, $p > .05$; and Path Efficiency, $F(2, 13) = .35$, $p > .05$. Finally, analysis of interaction between time and instructional groups found no significant difference on the Presence of Strategic Steps, $F(2, 13) = .52$, $p > .05$ (corrected for sphericity 0.81); Level of Strategic Steps, $F(2, 13) = .08$, $p > .05$ (corrected for sphericity .12); and Path Effectiveness and Efficiency, $F(2, 13) = .05$, $p > .05$ (corrected for sphericity .10).

It should be noted that the effect size of difference in Presence of Strategic Steps (partial $\eta 2 = .234$) and the corresponding p-value (.068), however the sample size was very small ($n = 16$), resulting in a lack of power in the repeated ANOVA test.

PRE Design Activity Scores		Mean (SD)
Instructor Led Instruction	Overall	7.25 (1.34)
Object focused Instruction Group	Overall	8.41 (1.12)

Table 15. Path effectiveness and efficiency for pre design activity scores.

	I feel learning SolidWorks is frustrating	My level of frustration impacts my ability to learn SolidWorks
Design Activity 1	F(2, 53) = .01, P > .05	F(2, 43) = .84, P > .05
Design Activity 2	F(2, 51) = .59, p > .05	F(2, 43) = .96, p > .05
Design Activity 3	F(2, 42) = .81, P > .05	F(2, 38) = 1.06, P > .05

Table 16. Responses to question on frustration.

Post Design Activity Additional Questions – Student Frustration and Design Activities

Two questions related to frustration were posed to students after each Design Activity. No significant differences were found between the groups. Those results are detailed and presented in Table 16.

Completing Activities Without The Tutorials

Students were asked if they would be able to complete the design activity without referencing any of the tutorials after each Design Activity. Table 17 presents the student responses across each design activity.

Student text comments provided a context for their yes/no responses. Students who did use the tutorials identified similar reasons across the conditions. Several students noted that they "had a hard time remembering what to do" and that "without the tutorials [they] would not have been able to come as close as [they] did to completing the objects" for the Design Activities. Reasons, as cited by students, may have been due to lack of familiarity with the software – e.g. "we did not have much practice [with some aspects of SolidWorks] … so [they] referenced the tutorials to complete [them]"; and that "remembering commands was difficult".

Some students chose not to use the tutorials knowing that asking the instructor instead would make completing the assignment 'quicker'. One student summed this up by stating, "If I had asked questions instead of rummaging through the tutorial, I could have evaded using [the tutorials]."

Post Design Activity 2		Instructor Led Instruction	Tutorial Focused Instruction	Object Focused Instruction	Total
Yes, I WOULD	Count	9	15	19	43
	% within Section	47%	75%	79%	68%
No, I would NOT	Count	10	5	5	20
	% within Section	52%	25%	20%	32%

Table 17. Ability to complete design activity 2 activities without the tutorials.

Other students, wanting to be autonomous in learning the software, noted they did not access the tutorials because they felt more comfortable “clicking around” to explore to find solutions or said that they had “retained enough from the tutorials and other experiences” that “a little trial and error helped me figure out what steps [they] needed to take.” On the other hand, several students noted that they preferred to ask questions saying “it was easier to simply ask the TA or the instructor questions [they] might have instead of accessing the tutorials”.

Perhaps the biggest shortcoming of the tutorials noted by several students was related to planning support. In the words of one student, while they “knew how to do everything, it was just a matter of deciding what [they] needed to do.” However, they “tried to use the tutorials … but the [connections] weren’t carrying over”. In other words, “The tutorial wasn’t helpful because I had to try to relate the concept on the tutorial to the assigned drawing and I really didn’t understand … so I couldn’t reconcile it to the drawing.”

Instruction Adequately Prepared Me

Students were asked if they felt that the SolidWorks instruction they received had adequately prepared them for the in-class design activities. No significant differences were found between the groups.

Student feedback regarding if the instruction they received adequately prepared them for the various design activities contained several repeating ideas that one student summarized as follows: “I should [be adequately prepared], as all the steps used [to create the object] were in the tutorial. However this does not account for recollection of the skills, which would account for the difficulty [I] had with the project. The difficulty then comes from lack of exposure [practice], not a lack of information.”

Changing Instruction Used to Teach SolidWorks

Students were asked if they would change the instruction that they received to learn SolidWorks to complete the in-class design activities. Logistical regression was conducted Post Design Activity 1, Post Design Activity 2, and Post Design Activity 3. No significant differences were found between the groups.

Students across the sections generally felt that “the instruction I received prepared me” and that “all the information I needed was given to me” because “I was able to complete the assignment.” However, students did note collectively that perhaps more practice, exercises, or more of [whatever] would be helpful to their overall learning. In terms of learning the software, one student phrased the overall challenge as “learn[ing] anything [is hard] when every week we’re trying to learn a new way to use the [CAD] program. There was very little repetition in the tutorials and rarely any chances to relate the new exercises back to something we already knew from the prior week.”

Accessing Tutorials to Complete the Activities

Students were asked to report how often they accessed the tutorials while working on each of the Design Activities. Given that for Design Activity 1, 87% of students did not respond; for Design Activity 2, 72% of students did not respond, and for Design Activity 3, 78% of students did not respond, those data are not reported here.

Student Identified Challenges Across Activities

Students in each group were asked "What were the biggest challenges you experienced while completing today's assignment?" Free text responses from students across the groups had two threads in common. Both threads were related to the new content that was being learned. First, each new Design Activity required specific knowledge and skill – and this was found to be a general challenge across the sections. This was evident in student responses, as students noted having difficulty with the same concepts. For example, students in each section noted that for Design Activity 1, they had difficulty shelling the object, mating the objects, drawing the object, and ordering the steps for the object. In Design Activity 2, students across the sections all noted that creating the handle, working with planes, doing sweeps, and lofting were difficult. Similarly, for Design Activity 3, common challenges across sections included sweeps, difficulty with dimensioning the object, changing units, and the time to complete the activity well.

The second thread, also related to learning, was the challenge of "remembering all the features" or "remembering all the details of how to do something". Recalling or knowing a command, where to access the command, and having it act on the object as anticipated formed the core of student comments.

DISCUSSION

Several interesting findings are worth noting. The responses on the Previous Experience Survey indicated that 1) students, *prior* to any instruction, at the outset of the course all had similar levels of programming experience and 2) that student confidence in their ability to create an object using SolidWorks was also similar. It would be plausible to posit, then, that the significant differences found between the groups could be a result of the section treatments. It is through this lens that we interpret the following significant findings.

Once instructional strategies were in place and the software was being taught; there was no significant difference in student confidence in any Pre- or Post- activity except PRIOR to Design Activity 1 where a significant difference in student confidence was observed. Students in the Instructor Led

Instruction group, who received step-by-step instruction, reported significantly higher confidence in their ability to do the design task than students in the Tutorial Focused Instruction Group and the Object Focused Instruction group. However, students in the Instructor Led Instruction group who received step-by-step instruction did *not* significantly outperform the other groups [achieve higher rubric scores] when assessed using the rubric. On the contrary, students in the Instructor Led Instruction group who received step-by-step instruction performed significantly poorer relative to strategic CAD knowledge than the students in the Object Focused Instruction group that generated a simple deliverable. These findings might suggest that providing Instructor Led Instruction and detailed step-by-step instruction when learning a software package may instill students with an inflated sense of confidence about their ability to effectively use that software. This appears especially true since student performance scores were not borne out as the student confidence scores might suggest. However, it should be noted that only prior to Design Activity 1 was student confidence significantly higher for the Instructor Led Instruction over the other groups, and performance of the Instructor Led Instruction group was significantly poorer only at the strategic knowledge level as compared to the Object Focused Instruction group. One might also infer that students in the Instructor Led Instruction Group realized they were perhaps over-confident and adjusted their perspective accordingly.

Of particular interest to this study are the results from the Pre Design Activity Rubric. The rubric served to assess three aspects, or dimensions of knowledge related to student ability to use the software. These dimensions, as noted earlier, included: the *presence of strategic steps,* indicative of declarative command knowledge; the *level of strategic steps,* indicative of procedural command knowledge; and the *path efficiency and effectiveness,* indicative of strategic knowledge of the software. Significant results were found related to each dimension or aspect of knowledge of student ability to use the software. A summary visualization of the results can be found in Table 18.

	The **PRESENCE** of Strategic Steps [declarative command knowledge]			The **LEVEL** of Strategic Steps [procedural command knowledge]			The **PATH** chosen [strategic use]		
Tutorial Focused Instruction Group					Performed significantly HIGHER than				
Object Focused Instruction Group	Performed significantly HIGHER than								Performed significantly HIGHER than
	Tutorial Group	Object Group	Instructor Group	Tutorial Group	**Object** Group	Instructor Group	Tutorial Group	Object Group	**Instructor** Group

Table 18. Visual summary of pre design rubric results.

The *presence of strategic steps*, represented student ability to recognize, identify, and state the steps necessary to create the assigned object, which is reflective of the students' declarative command knowledge of the software. Looking across these findings may reveal results one might not expect. Of the instructional strategies focused on for this investigation, we found that Object Focused Instruction, had a significant impact on student declarative command knowledge i.e. the ability to recognize, identify, and state the steps necessary to create the assigned object compared to the Tutorial Focused Instruction group. This may indicate that having students generate a simple deliverable *immediately* at the end of an instructional activity may help students to develop declarative command knowledge of the software and help them identify, recall and retain basic CAD command information. The focus on 'object creation' may lend to the impression that object development is a multi-step linear process instead of a series of sequenced and potentially interchangeable sub-steps. A reasonable assumption would have been to suspect that Tutorial Focused Instruction might best reinforce and support the development of declarative command knowledge, given that tutorials focus on and highlight the individual steps that comprise the procedures needed to accomplish specific tasks [i.e. declarative command knowledge]. But this does not seem to be the case. While a significant difference was found between the performances of students in the Object focused Instruction group related to declarative knowledge; no significant difference on the dimension of presence of strategic steps was noted between Object Focused Instruction and Instructor Led Instruction. It could be inferred from these findings that Object Focused Instruction may be a best support strategy in developing student declarative knowledge of the software and Tutorial Focused Instruction is least suited to supporting student development of declarative knowledge of the software. It would be interesting to determine if it is reasonable to infer that Object Focused Instruction best supports student development of declarative command knowledge related to CAD software.

A significant difference in performance associated with the *level* of strategic steps was noted across all three activities. We found that Tutorial Focused Instruction had a significant impact on students' procedural command knowledge i.e. the ability to group or chunk individual steps into a series of larger steps or procedures, which is reflective of the students' procedural command knowledge of the software compared to the Object Focused Instruction group. Students in the Object Focused Instruction group were *less* successful in the ability to iterate and describe the procedural command knowledge necessary to generate and produce the Design Activity object than the students in the Tutorial Focused Instruction group. At first blush, this may seem counter intuitive, but it could be argued that students in the Tutorial Focused Instruction group, who focused primarily on the tutorials, having repeatedly accessed needed information in a formalized and structured way, were better able to formalize or describe their own process as a set of organized steps. Students in the Tutorial Focused Instruction group experienced the explanatory steps in procedures by reading and reviewing the steps repeatedly, in sequenced and broader contexts. One might infer that the nature and composition of the tutorials [non-segmented], when coupled with tutorial focused instruction, supports student ability to cultivate procedural command knowledge of the software as compared to an Object Focused Instructional approach that focuses on generating and creating an object immediately at the end of each class session. The focus on 'object creation' may have detracted from student ability to 'see' the individual steps of object development as belonging to a larger set of sub-processes. A reasonable assumption in this instance might have been to assume Object Focused Instruction might best facilitate the development of procedural command knowledge given that students are focused on directly executing and applying procedural commands when creating objects. One might even conjecture that Instructor Led Instruction might best facilitate the development of procedural command knowledge since students benefit from the instructor highlighting and explaining the instructional procedures associated with the software i.e. making the procedural commands explicit. However, the significant performance difference at the procedural command dimension noted for the Tutorial Focused Instruction did not carry over to students in the Instructor Led Instruction group. One might be tempted to infer that Tutorial Focused Instruction is most successful at supporting student development of procedural command knowledge of CAD software – significantly so when compared to Object Focused Instruction; but not significantly so compared to Instructor Led Instruction. Object Focused Instruction then appears to be the least successful strategy for teaching procedural commands under these conditions.

A third significant difference, as we look across these instructional strategies, found that Object Focused Instruction had a significant impact on students strategic use of the software i.e. student ability to choose paths through the software that are efficient and effective related to the task to be performed in SolidWorks. Students in the Object Focused Instruction group, who had to produce a deliverable at the end of every class session, were significantly better able to iterate and describe strategic knowledge related to the SolidWorks software than those students in the Instructor Led Instruction group. One might have predicted that students in the Instructor Led Instruction group would have had the advantage related to iterating and describing strategic use of the software given the instructor's expertise and detailed explanations that modeled and provided insight and guidance for student thinking related to manipulating the software. This result might suggest that requiring students to complete simple discreet objects as part of a larger plan or object may better support students in their ability to deconstruct larger more complex objects, hence using the program more effectively. While students may see this as 'double' work, the results found in this study suggest that creating a separate object replicating the concepts stressed in instruction *immediately* after instruction, may contribute to students overall ability to think strategically with the software. In light of the findings, it seems reasonable that focusing on the object to be created is aligned with developing a strong sense of strategic knowledge of the software. However, it is interesting that student performance on this knowledge dimension was significantly different only in comparison to the Instructor Led Instruction group. No significant difference in performance was found for the dimension of strategic use when compared to students in the Tutorial Focused Instruction group.

A final significant result concerns a question from the Post Design Survey after Design Activity 2. This question asked students if they would have been able to complete the Design Activity without referencing the tutorials. Almost eighty percent of the students in the Object focused Instruction Group noted that they would have been able to complete the day's assignment without referencing the tutorials to create the object, compared to less than half [forty seven percent] of the students in the Instructor Led Instruction Group who felt they would have been able to complete the design assignment without referencing the tutorials to create the object. In other words thirty two percent more students in the Object Focused Instruction Group felt they could complete the design assignments without referencing the tutorials when compared to the students in the Instructor led Instruction Group.

A natural extrapolation of this finding would be to surmise that students in the Instructor Led Instruction group might perceive themselves to be, upon reflection, less self-reliant and more dependent upon on the tutorial supports. Similarly, the students in the Object Focused Instruction group may perceive themselves, upon reflection, as more self-reliant and capable, and thus able to complete the task unaided. This extrapolation is also supported by the students self-reported confidence scores. Further investigations should be conducted however as this result occurred only in Post Design Activity Survey 2.

Further research should be conducted to explore the 'strategic use' of various instructional strategies. Understanding 'how' and 'when' specifically focused instructional strategies should be employed to optimize student learning is relevant to both instructional success and student success in the workplace. The results summarized above may suggest that providing students with Instructor Led Instruction may bolster student confidence, but does not significantly improve student performance. Perhaps Instructor Led Instruction should be utilized early in instruction with the caveat that the instructor does not need to spend large amounts of class time explaining and detailing aspects of the software. Focusing on developing individual objects seems to foster student development of declarative software knowledge and may be best used as unguided or homework activities. Class time *with* the instructor might be better allocated to providing supplemental object development opportunities in addition to tutorial objects *prior* to homework assignments to bolster the development of declarative software command knowledge. Providing in class support for Tutorial Focused Instruction to support student development of procedural command knowledge may best support the development of procedural command knowledge. Allowing class time for object development post instruction may best support students in developing procedural knowledge, affording the opportunities to foster student development strategic software knowledge.

When writing this article, we were asked to speculate on why the differences we found *only* occurred in the pre design activity and not in the post design activity. We posit the following for consideration. We have suggested that is critical for design engineers to have knowledge of and proficiency with 3D parametric modeling software. This knowledge and proficiency [the overarching goal of instruction] has been described as the ability to 'think strategically' with the software. The components of strategic thinking have been described as the ability to plan, predict, operate under a set of assumptions, and consider alternatives. In theory then, strategic thinking with the software is the ability to correctly envision the operations and procedures needed to create the design object and anticipate effectively how to execute operations and procedures. For this investigation we have operationalized this as 1) identifying the steps or commands needed to create a design object, 2) executing those commands as command processes or procedures, and 3) sequencing those processes and procedures based on a set of design options and constraints.

We have also argued that it is important to measure or assess student ability to strategically think with CAD software. Since strategic thinking with the software is reflective of a student's ability to plan, predict, and think ahead as to what procedures and processes are required or appropriate for the design – then assessment of student ability needs to be collected as a descriptive thought process in anticipation of, or prior to, executing the design plan i.e. creating the physical design object. Collecting these descriptive processes of what the student *plans* to do BEFORE the student actually executes that plan [constructs the design object] is 'true' evidence of student ability to strategically think with the software. Collecting this same evidence AFTER the design activity – or after the student has had the opportunity to operationalize [adjust, verify, correct, adapt] their thinking [plan], only recounts the *production* of the object and does not capture the intended plan or *process* of the design. This aligns with our initial argument that the current assessment practice does evaluate evidence of strategic thinking in design. It would follow then that if we wish to measure the impact of various instructional strategies on the ability to promote strategic thinking in students, this assessment – a description of what the student plans to do – needs to be collected BEFORE the student executes the plan for the design object. Again, collecting this description after the student has created the design object is essentially a description of the proof of concept – and not a description of the original plan. It would follow then, if variance in effectiveness of the instructional strategies related to that strategy's effectiveness to support dimensions of strategic thinking is going to occur; then those differences would be seen in the Pre-Design Activity. It is reasonable to argue then that no differences would be found AFTER the design activity in the descriptions of what was actually done as the students have actively confirmed or denied the predictions/plan that was proposed to generate the design object. In other words, the students have had the opportunity DURING the design activity, to identify and correct any misconceptions or mistakes they may have had. In sum, the Pre Design Activity Rubric

Score is the assessment of student strategic thinking and evaluation of the student's design plan. The Post Design Activity Rubric Score is the assessment and confirmation of the student's activity as proof of concept – the confirmation/correction of the adjusted or modified student plan.

In closing, while we found that each of the instructional strategies did benefit specific dimensions that constitute strategic thinking with CAD software; no one instructional strategy appeared to be clearly more effective at promoting a specific knowledge dimension over the other two instructional strategies. However, it does appear that these finding may help to inform how to balance and insert these strategies in the overall instructional plan.

REFERENCES

1. Nikos J. Mourtos, "Teaching Engineering Design Skills," (presentation, International Engineering and Technology Education Conference, Kuala Lumpur, Malaysia, 2011).

2. Herbert A. Simon, *The Sciences of the Artificial* (Cambridge: MIT Press, 1981).

3. Clive L. Dym, *Engineering design: a Synthesis of Views* (New York: Cambridge University Press, 1995).

4. ABET, Engineering Accreditation Commission of the Accreditation Board for Engineering Technology. 2000–2001. Criteria for Accrediting Engineering Programs. Baltimore, MD.

5. Aristides A. Requicha & Jarek R. Rossignac, "Solid Modeling and Beyond," *Computer Graphics and Applications*, IEEE vol. 12 no. 5 (Sep 1992).

6. Atila Ertas & Jesse C. Jones, *The Engineering Design Process* 2nd ed. (New York: John Wiley & Sons, Inc., 1996).

7. Krystal S. Corbett, Heath Tims, Galen E. Turner, James D. Nelson. "Utilizing the Engineering Design Process to Create a Framework for Curricula Design" (presentation, American Society for Engineering Education, 2012).

8. Theodore J. Branoff & Nathan W. Hartman, "The 3D Model Centered Curriculum: How Do We Prepare Our Students?" (presentation ASEE Southeast Section Conference, 2002).

9. Theodore J. Branoff, Nathan W. Hartman, & Eric N. Wiebe, "Constraint-Based, Solid-Modeling: What Do The Employers Want Our Students to Know?," *The Engineering Design Graphics Journal* vol. 67, no. 1 (2003).

10. Ivan Chester, "Teaching for CAD Expertise," International Journal of Technology and Design Education vol. 17 (2007): 23–35.

11. Loizos Heracleous, "Strategic Thinking or Strategic Planning," *Long Range Planning* vol. 31, no. 3 (June 1998).

12. Jeanne Liedtka, "Linking Strategic Thinking with Strategic Planning," *Strategy and Leadership* vol. 1 (October 1998).

13. Lorin W. Anderson & David R. Krathwohl. (Eds.). *A taxonomy for learning, teaching and assessing: A revision of Bloom's Taxonomy of educational objectives: Complete edition*. (New York: Longman, 2001, 67–68).

14. Michael S. Matell & Jacob Jacoby. "Is there an optimal number of alternatives for likert scale items? Study I: reliability and validity," *Educational and Psychological Measurement 31* (1971): 657–674.

15. Takafumi Wakita, Natsumi Ueshima, & Hiroyuki Noguchi, "Psychological distance between categories in the likert scale: Comparing different numbers of options," *Educational and Psychological Measurement 72, no.* 4 (2012): 533–546.

16. Anselm Strauss & Juliet Corbin, *Basics of Qualitative Research*: *Grounded Theory Procedures and Techniques*, 2nd ed. (Thousand Oaks: Sage Publications, 1998).

17. Matthew B. Miles & A. Michael Huberman, *Qualitative Data Analysis* (Thousand Oaks: Sage Publications, 1994).

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APPENDIX A: PREVIOUS EXPERIENCE SURVEY

1. What is your gender? O Male O Female
2. Please indicate the extent of your DRAFTING and CAD experience PRIOR to EDSGN 100 below:

	No experience	< 1 Yr.	1–2 Yrs.	2–3 Yrs.	3–4 yrs.	5 + yrs.
DRAFTING experience	O	O	O	O	O	O
CAD experience	O	O	O	O	O	O
Using SolidWorks	O	O	O	O	O	O
Using Auto-CAD	O	O	O	O	O	O
Using other: [enter software used below]	O	O	O	O	O	O

3. Please indicate your level of confidence at THIS moment to the following question:

   How confident are you in your ability to construct an object in class today using SolidWorks:

   Not at all Confident ....Highly Confident

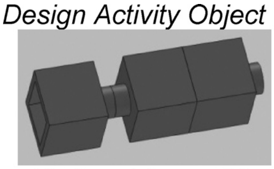
   0 1 2 3 4 5 6 7 8 9 10

APPENDIX B: DESIGN ACTIVITY OBJECTS

In each of the Design Activity instances students were asked:

Using the example you have been given as a guide, describe the strategic steps you would use to create the following object[s].

Design Activity Object 1

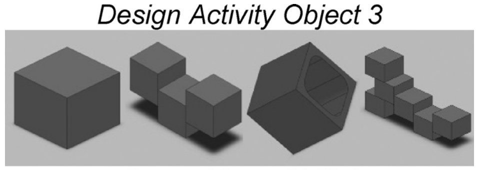


Part and Assembly

Design Activity Object 2

Mug and Bottle

Design Activity Object 3



Assembly and Fillet

APPENDIX C: POST DESIGN ACTIVITY SURVEY

Common Questions to BOTH the Pre and Post Assignment Survey

1. How confident are you in your ability to construct an object in class today using SolidWorks :

   [Not Confident At All 0 1 2 3 4 5 6 7 8 9 10 Highly Confident]

2. Using the guide for describing the strategic steps you would take to generate the example object; Referring to the handout you have been given, please list and describe the strategic steps you would take to construct the object for today's assignment
*Responses were graded using the rubric

The Post-Assignment Survey Items: Additional Questions

1. Please indicate the number of times that you accessed the tutorials while working on the object for today's assignment. [0-5 or more]

2. Would you have been able to complete the assignment today without referencing any of the tutorials [Yes/No]
   a. If Yes (please explain below
   b. If No (please explain below)

3. Did the SolidWorks instruction you received prior to this class activity adequately prepare you for the assignment today? [Yes/No]
   a. If Yes (please explain below
   b. If No (please explain below)

4. How would you change the instruction you have received prior to working on the class activity today?
   a. I WOULD NOT change the instruction prior to this activity… (please describe below)
   b. I WOULD change the instruction prior to this activity… (please describe below)

5. What were the biggest challenges that you experienced with completing today's assignment? [open ended]

6. Please indicate how true the following statements about SolidWorks are using the scale below: [0-10]
   a. I feel learning SolidWorks is frustrating
   b. My level of frustration with learning SolidWorks impacts my ability to master SolidWorks (2)

APPENDIX D: DESIGN ACTIVITY RUBRICS FOR SCORING STUDENT RESPONSES

* The most efficient and effective paths are being determined based on expert results and time efficiency as shown in each rubric below:

1st Activity Rubric	[low] 1	SCORE 2	[high] 3	4	
Presence of Strategic Steps	0	*1-2*	*3-5*	*6-7*	// # of strategic steps
Part	0	*1*	*2*	*3*	
Assembly	0	*1*	*2*	*3-4*	
Steps listed at the correct level	20 +	*14-19*	*8-13*	*0-7*	// # of steps grouped w/each strategic step
Part	10 plus	*7-9*	*4-6*	*0-3*	
Assembly	10 plus	*7-9*	*4-6*	*0-3*	
Set path was efficient	0	*1-2*	*3-5*	*6*	// Based on path they follow*
Part	0	*1*	*2*	*3*	
Assembly	0	*1*	*2*	*3*	

Part: [3 steps]	**3**	*Extrude Prism --> Extrude Cylinder --> Shell the Object*
	2	*Extrude Prism --> Extrude Cylinder --> Extrude Cut Object*
	1	*Extrude Cylinder --> Extrude Prism --> Shell the Object*
	0	*Extrude Cylinder --> Extrude Prism --> Extrude Cut Object*
Assembly: [3-4 steps]	**3**	*Insert 3 Blocks --> Mate Bottom Blocks --> Mate Top Blocks*
	2	*Insert 3 Blocks --> Mate Top Blocks --> Mate Bottom locks*
	1	*Insert 2 Blocks --> Mate Bottom Blocks --> Insert 3rd Block --> Mate Top Blocks*
	0	*Insert 2 Blocks --> Mate Top Blocks --> Insert 3rd Block --> Mate Bottom Blocks*

2nd Activity Rubric	[low] 1	SCORE 2	3	[high] 4	
Presence of Strategic Steps	0	1-2	3-5	6-7	// # of strategic steps
Mug	0	1	2	3(2*)	* 2 SS if revolving cylinder
Bottle	0	1	2	3	if {lofting bottle}
	0	1-2	3-4	5	if {using extrude}
Steps listed at the correct level	20 plus	14-19	8-13	0-7	// # of steps grouped with each strategic step
Mug	10 plus	7-9	4-6	0-3	
Bottle	10 plus	7-9	4-6	0-3	
Set path was efficient	0	1-2	3-5	6	// Based on path they follow*
Mug	0	1	2	3	
Bottle	0	1	2	3	

Mug:	**3**	Extrude Solid Cylinder --> Shell the Mug --> Sweep Handle
		Revolve Cylinder --> Sweep Handle
	2	Extrude Solid Cylinder --> Extrude Cut Mug --> Sweep Handle
		Extrude Hollow Cylinder --> Extrude Solid Base --> Sweep Handle
		Extrude Base of Mug --> Extrude Hollow Cylinder --> Sweep Handle
	1	Loft Solid Cylinder -->Shell the Mug --> Sweep Handle
	0	Loft Solid Cylinder --> Extrude Cut Mug --> Sweep Handle
Bottle:	**3**	Loft Bottle --> Fillet Edges --> Shell Bottle
	2	Loft Bottle --> Shell Bottle --> Fillet Edges (w/ rollback)
	1	Extrude Base --> Loft Middle --> Extrude Top --> Fillet --> Shell
	0	*above in any other order*

3rd Activity Rubric	[lowest] 1	SCORE 2	3	[highest] 4	
Presence of Strategic Steps	0	1-2	3-5	6-7	// # of strategic steps
Assembly	0	1	2	3-4	
Fillet	0	1	2	3(2*)	*if{sketch fillet}
Steps listed were at the correct level	20 or more	14-19	8-13	0-7	// # of steps grouped with each strategic step
Assembly	10 or more	7-9	4-6	0-3	
Fillet	10 or more	7-9	4-6	0-3	
Set path was efficient and effective	0	1-2	3-5	6	// Based on path they follow*
Assembly	0	1	2	3	
Fillet	0	1	2	3	

Assembly:	**3**	Insert 3 Blocks --> Mate Bottom Blocks --> Mate Top Blocks
	2	Insert 3 Blocks --> Mate Top Blocks --> Mate Bottom locks
	1	Insert 2 Blocks --> Mate Bottom Blocks --> Insert 3rd Block --> Mate Top Blocks
	0	Insert 2 Blocks --> Mate Top Blocks --> Insert 3rd Block --> Mate Bottom Blocks
		any of above creating a new block instead of opening Extrude
Fillet:	**3**	Open Extrude --> Shell --> Fillet
	2	Open Extrude --> Extrude Cut Square --> Fillet
		Open Extrude --> Extrude Cut Hole Profile
	1	Extrude Plate --> Extrude Hollow Block --> Fillet
	0	*any of above creating a new block instead of opening Extrude*

LOW SCORING EXAMPLE DECONSTRUCTION

BENCHMARK RESPONSE *PART*	LOW SCORING EXAMPLE
1 Extrude prism	Open up solid works. Open new parts document. Click on sketch. Click on rectangle button. I Select corner rectangle. Select front plane. I Start at origin and drag out creating a rectangle. I Click on smart dimensions. I First click on horizontal blue line. I Pull out dimension lines of rectangle. I Add dimensions to that line. I Click on vertical blue line. I Pull out dimension lines out of rectangle. IAdd dimensions. IClick on extrude boss/base. IType in height. IClick on front face of object
2 Extrude cylinder	Click on circle button. I Draw circle. I Click on smart dimensions. IClick on outside blue line of circle. I Type dimension. IClick center dot. I Click on vertical edge and type dimension. IClick on center dot again. IClick on horizontal line and type dimension. I Click on feature. IClick extrude boss/base. IType dimension.
3 Shell object	Click on shell. IClick on back of object. I Type dimension. Save.
ASSEMBLY	
1 Insert 3 blocks	Open new document. Click on assembly part 1. I Pull in assignment 1. IClick on insert object. I Pull in assignment 2 Click insert object
2 Mate bottom blocks	Click on mate buttonI. Click on back face of part. I Click on back face of another part. I Click coincident. I Click anti-aligned. Click okI. Click mate click the same face of both objects that are already mated then click parallel. I Click okI. Click top face of both objects that are now mated twiceI. Click coincident. I Click ok.
3 Mate top blocks	Click on round face of last free part. I Click on round face one of the connected parts. I Click coincident. IClick anti-aligned. I Click ok. IClick face three of two part object and the last free part. Click coincident. Click ok. IClick face one of part 1. I Click face 2 of parts. I Click coincident. I Click ok.

		APPLIED RUBRIC SCORE 1	2	3	4
DIMENSION 1:PRESENCE of Strategic Steps		**0**	**1-2**	**3-5**	**6-7**
	Part	0	1	2	3
	Assembly	0	1	2	3-4
DIMENSION2: Listed steps were at correct LEVEL		**20 +**	**14-19**	**8-13**	**0-7**
	Part	10 +	7-9	4-6	0-3
	Assembly	10 +	7-9	4-6	0-3
Dimension 3: Set PATH was efficient and effective		**0**	**1-2**	**3-5**	**6**
	Part	0	1	2	3
	Assembly	0	1	2	3

DIMENSION 1
Student listed actions for the part can be identified with each of the 3 strategic needed to complete the part – **part score=3**.

Student listed actions for assembly are incomplete for the 3rd step. *Did NOT list mating the 3rd top block* – **assembly score=2**.
Part Score + Assembly Score =5
Earning a **DIMENSION 1 rubric score of 3**

DIMENSION 2
Listed actions to create the part > 10 – **part score=0.**
Listed actions to create the assembly > 10; **assembly score=0**.
Part Score + Assembly Score =0
Earning a **DIMENSION 2 rubric score of 1**

DIMENSION 3
Path to create the part was optimal and correct – **path score=3.**
Path to create the assembly is incomplete for the assembly.
3rd strategic step is incomplete so path in complete **assembly score=1**
Part Score + Assembly Score =4
Earning a **DIMENSION 3 rubric score of 3**

HIGH SCORING EXAMPLE DECONSTRUCTION

BENCHMARK RESPONSE *PART*	HIGH SCORING EXAMPLE
1 Extrude prism	Create new part. Sketch a rectangle and add dimensions. I Extrude boss the rectangle
2 Extrude cylinder	Sketch a circle on the one face of the cube. I Dimension the circle. Extrude boss the circle
3 Shell object	Hollow out the part. Save the part
ASSEMBLY	
1 Insert 3 blocks	Create new assembly. Add previous part to the assembly 3 times
2 Mate bottom blocks	Mate the front face circle to the front face circle. Mate left side of cube with corresponding side of rotated part.
3 Mate top blocks	Mate back face of hollowed out cube with same side on third part. Mate left side of rotated cube with corresponding side of third part

		APPLIED RUBRIC SCORE 1	2	3	4
DIMENSION 1: Presence of Strategic Steps		**0**	**1-2**	**3-5**	**6-7**
	Part	0	1	2	3
	Assembly	0	1	2	3-4
DIMENSION 2: Listed steps were at correct level		**20 +**	**14-19**	**8-13**	**0-7**
	Part	10 +	7-9	4-6	0-3
	Assembly	10 +	7-9	4-6	0-3
DIMENSION 3: Set path was efficient and effective		**0**	**1-2**	**3-5**	**6**
	Part	0	1	2	3
	Assembly	0	1	2	3

DIMENSION 1
Student listed actions for the part can be identified with each of the 3 strategic needed to complete the part – **part score=3**.

Student listed actions for assembly can be identified with the 3 strategic steps to complete the assembly – **assembly score=3-4**.
Part Score + Assembly Score =6-7
Earning a **DIMENSION 1 rubric score of 4**

DIMENSION 2
Listed 4-6 actions to create the part – **part score=4-6.**
Listed 4-6 actions to create the assembly – **assembly score=4-6**.
Part Score + Assembly Score =8-13
Earning a **DIMENSION 2 rubric score of 3**

DIMENSION 3
Path to create the part was optimal and correct – **path score=3.**
Path to create assembly was optimal and correct – **assembly score=3**
Part Score + Assembly Score =4
Earning a **DIMENSION 3 rubric score of 4**