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The Relative Pedagogical Value of Disassemble/Analyze/Assemble (DAA) Activities

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ABSTRACT

Inherently a discovery-based pedagogy, Disassemble/Analyze/Assemble (DAA) activities start with the artefact, an instance of a typically well-engineered solution. Through systemized disassembly and the subsequent analysis of components, students engage in an iterative process of observation and follow-up probing. In-turn, this process helps students understand the function of the artefact's components and their interconnection with each other and the operation of the artefact. Previous studies have provided highly descriptive accounts of curricula outcomes of DAA activities; but relatively few have compared participants doing DAA activities to a control group learning the same content in a more traditional fashion. To address this issue, a quasi-experiment was conducted as part of a first-year engineering laboratory, where a DAA activity was compared to a lecture on the same content. The results showed that students who engaged in the DAA activity were more motivated and demonstrated higher frequencies of transfer than those receiving lecture. Superior transfer by the DAA condition was found even after controlling for prior knowledge of the transferrable element.

Key Words: disassembly, transfer, motivation, discovery-based pedagogy

INTRODUCTION

To achieve mastery of the fundamental ideas of a field, Bruner suggests that in addition to grasping the general principles, one must also "develop an attitude towards learning and inquiry, towards guessing and hunches, towards the possibility of solving problems on one's own" (1977, p. 20) Although uncertain at the time about the required approach for instilling these crucial attitudes in learners, Bruner expressed a lack of confidence in the adequacy of the mere presentation of ideas. Instead, he pushed for the inclusion of discovery, the process whereby regularities of previously unrecognized relations and similarities between ideas are uncovered by the learner, resulting in a sense of self-confidence in one's abilities. Advocates of discovery learning tend to support Piaget's assertion that ''each time one prematurely teaches a child something he/she could have discovered for himself/herself, that child is kept from inventing it and consequently from understanding it completely'' (Piaget, 1970, p. 715). Following the publication of Bruner's Art of Discovery (1979), a flurry of research on discovery based pedagogical methods ensued (Mayer, 2004). Many studies entailed comparisons among pure discovery methods where students were required to solve problems with little or no guidance; guided discovery methods where hints, direction, coaching, feedback, and/or modeling were provided to keep the student on track; and expository methods where students were given the problem along with the correct answer. Scholars such as Schwartz, Bransford, and Sears (2005) found that innovation or discovery-oriented activities are instrumental to deep understanding and transfer. Others, such as Klahr and Nigam (2004) and Kirschner, Sweller and Clark (2006), argue in favor of direct instruction, finding that discovery learning simply takes longer, mainly benefits top-achievers or those with sufficiently high prior knowledge, and can lead to the development of misconceptions.

In spite of the ongoing debate, active engagement and motivation have emerged as undisputed features of discovery-based learning; however, one of the main sources of contention lies in the inability of the approach to constrain students' exploration without guidance. What students self-discover may not always be what was intended to be taught. For example, actively constructing objects is not necessarily the same as constructing an understanding of how they work. Students may demonstrate their ability to make a model rocket but develop little understanding of aerodynamics. The concern then is that discovery activities take time and may not provide sufficient parameters to direct students' attention to topic-relevant concepts.

DISASSEMBLE/ANALYZE/ASSEMBLE (DAA) ACTIVITIES - REVERSE DISCOVERY

Inherently a discovery-based pedagogy, Disassemble/Analyze/Assemble (DAA) activities start with the artefact, an instance of a typically well-engineered solution. Through systemized disassembly and the subsequent analysis of components, students engage in a potentially self-directed iterative process of observation and follow-up probing. In turn, this process helps students understand the function of the artefact's components and their interconnection with each other and the operation of the artefact. Typical discovery activities such as inventing or construction tend to be flawed by their inability to constrain students' explorations and prevent deviation from the intended focus. DAA activities attempt to overcome this challenge by starting with the expert version, an approach that has shown success at facilitating learning, transfer, and motivation (Dalrymple, Sears, & Evangelou, 2011).

DAA activities are well suited for engineering education given the relationship between engineering and artefacts. Engineering thinking is materialized largely through interactions with artefacts, the material aspects of our physical world. Engineers interact with artefacts as creators, bringing them into existence; curators, maintaining and furthering them; and controllers, extending knowledge and access of and to these artefacts. Studying the pedagogical affordances of this type of artefact interaction (i.e., DAA Activities) can continue to extend our understanding of discovery-based learning pedagogies with the additional potential to reveal new ways in which we can specifically nurture engineering thinking.

DAA ACTIVITIES IN ENGINEERING EDUCATION

The application of DAA activities in engineering learning environments has generated rave reviews from both instructors and students. Starting in 1991 with the work by Sheri Sheppard in her mechanical engineering dissection course at Stanford University, the following learning outcomes have been associated with the use of DAA activities: helping students identify relationships between theoretical concepts and their real-world instantiations (Brereton, Sheppard, & Leifer, 1995), increasing motivation and retention (Carlson, Schoch, Kalsher, & Racicot, 1997), encouraging the development of curiosity, proficiency and dexterity (Beaudoin & Ollis, 1995; Hess, 2002), providing hands-on activities to couple engineering principles with significant visual feedback (Barr, Schmidt, Krueger, & Twu, 2000; McKenna, Chen, & Simpson, 2008), and supporting design learning (Devendorf, Lewis, Simpson, Stone, & Regli, 2007; Ogot, Okudan, Simpson, & Lamancusa, 2008; Wood, Jensen, Bezdek, & Otto, 2001).

One of the noted shortcomings of the current literature on DAA activities is the lack of empirical evidence from controlled experiments that indicate the advantages of DAA pedagogies over other traditional forms of instruction. In response to this need, recent explorations conducted by the authors into the pedagogical viability of DAA activities, have experimentally confirmed the potential of DAA activities to elicit motivation over more traditional forms of instructions (i.e., step-by-step lab instructions) and identified its additional benefit to promote transfer to novel design problems

(Dalrymple et al., 2011). A follow-up study, which is described in this publication, extends on the authors' initial findings by further isolating the factors in DAA activities that are instrumental to students' learning and motivation in engineering.

CONTRIBUTIONS OF THE STUDY

In a previous experiment, a DAA activity was compared to a different engineering technique for their respective abilities to foster motivation and transfer of learning (Dalrymple et al., 2011). Results revealed that the DAA activity promoted greater motivation and transfer, but, relevant to the current study, it also pushed for learning different content. The DAA activity supported the learning of specific part-function relationships while the control condition supported greater breadth. This raised the concern that if the content that was emphasized by each condition was different, the results for the DAA activity could simply be due to its attention to part-function relationships rather than what we consider to be the hallmark of DAA activities—direct manipulation of an artefact. In addition, the previous study only used one measure of transfer and a three-question measure of motivation, so the degree of generalizability of the findings required further testing. In the current study, a DAA activity is compared to a direct method of instruction i.e., lecture. Both instructional methods are designed to help students learn the same content knowledge because both address part-function relationships. This improved comparability from the previous study allows for evaluations on multiple dimensions of learning (e.g., factual recall of part-function relationships and multiple measures requiring redesign or knowledge transfer). With this level of control, any resulting significant differences between conditions suggest benefits inherent to the manipulative process in DAA activities. In addition, well-established measures of motivation were added to the previous measures to ensure a more complete picture of the effects of DAA activities.

DAA VERSUS DIRECT INSTRUCTION

In the first U.S. edition of Donald Bligh's "What's the Use of Lectures?"(2000), a lecture is defined as "a period of more or less continuous exposition by a teacher." Bligh also provides the outcomes of numerous experimental comparisons to substantiate the claim that lectures are as effective as other methods of instruction for transmitting information. He also goes on to validate in the same manner that lectures are not as effective as discussion methods for the promotion of thought, and relatively ineffective for inspiring interest in a subject. Thought as described by Bligh can be likened to the cognition or deeper understanding required to enable transfer to novel problems, and interest in a subject matter likened to motivation. A key difference between lecture and DAA methods of instruction is that even if the factual content is the same, the DAA method is expected to afford more opportunities for students to think about the interconnection of parts and functions because they must attend to these while disassembling an artefact, especially if the goal is to understand the design of the artefact. In this sense, the manipulation of the artefact and the learning of part-function relationships are directly interconnected in DAA, perhaps lending greater meaningfulness and motivation to the DAA activity. Hence it is within reason to expect the outcomes achieved in the previous experiment (Dalrymple et al., 2011) to persist. For the current study it was hypothesized that on measures of motivation, the DAA activity will be rated higher than the lecture; on measures of learning where the task required students to recall the part-function relationships explored in both instructional approaches, the DAA activity and lecture will result in equivalent performance; and on measures of deeper understanding, like the application of knowledge to redesign or defect diagnosis tasks, the DAA activity will result in greater transfer.

METHODS

The study was conducted within the context of a laboratory, following approval from the Institutional Review Board. The laboratory was designed to introduce first-year engineering students to the principles of design for the environment (DfE) through the study of a Fujifilm single-use camera. DfE refers to the systematic consideration of design performances with respect to environmental, health, and safety objectives over the full product life cycle. Fujifilm applies these principles in the design and development of its line of single-use cameras. The single-use cameras are produced in an inverse manufacturing facility where 99% of used cameras are either remanufactured or recycled to produce new generations of the product. Both a lecture and a DAA activity were utilized to help students learn about the design of the camera. With the DAA activity, students disassembled the camera and analyzed its components to discover their function and interconnectedness, while the lecture presented similar content with the use of a multimedia PowerPoint presentation. To measure and compare the learning outcomes from each instructional method, yet ensure all students had an equivalent learning experience, the lab was completed in one of two sequences: 162 students did the DAA activity before the lecture (Sequence 1 – DAA First) and 163 students had the lecture before the DAA activity (Sequence 2 – Lecture First). Assessment activities, administered online, and completed by each student individually, preceded and followed each instructional method. The assessments were used to measure the extent to which the DAA activity and the lecture facilitated learning and

Duration	Task #	Sequence 1 (DAA First)	Sequence 2 (Lecture First)	Task Type
8 min	-	Introduction		Class
10 min	1	Pretest - Match Components to Functions		Individual
30 min	2	DAA Activity	Lecture	Team/Class
20 min	3	Posttest 1 - Variant Design, System Decomposition & Camera Doctor		Individual
30 min	4	Lecture	DAA Activity	Class/Team
5 min	5	Posttest 2 - Unwanted Features		Individual
7 min	-	Post Lab Survey		Individual

Table 1. Study design/task sequencing.

transfer of knowledge about the function and interconnectedness of the components used in the camera's design. To ensure consistency in the facilitation of the lab, particularly the presentation of the lecture, all labs were led by the same person. Table 1 shows the design of the study and the sequence of tasks in the lab. Each lab task is described in the following sections.

Introduction

The lab began with an 8-minute PowerPoint presentation. In the presentation, DfE was described and demonstrated in the design and development of Fujifilm's line of QuickSnap single-use cameras. Students were also given an overview of the lab tasks to follow and procedural instructions for accessing the online assessments.

Task 1 (Pretest)

The first task was the same in both sequences, and it served as the pretest. It provided a measure of student's prior knowledge of the part-function relationships of the single-use camera that was studied in the lab. For the task, students were asked to match the components of the camera to their functions. Each of the eight questions contained a different function description and pictures of eight components from the Fujifilm QuickSnap Outdoor 1000 single-use camera. Students were instructed to select the component that fulfilled the described function.

Task 2

The second task was either the DAA activity (Sequence 1 / DAA First) or the lecture (Sequence 2 / Lecture First). For the DAA activity, students worked in teams of 3-4 students. Each team was given an instruction sheet that introduced the concept of reverse engineering and its application in industry as a tool used by companies to compare their services and practices to competitors. Also included was a description of a fictitious company interested in developing a line of single-use cameras that wanted to learn more about the design of the Fujifilm single-use camera. Students were asked to assist in this venture by working in teams to systematically disassemble a Fujifilm QuickSnap Outdoor 1000 camera. They were also asked to use any representation of their choice to record the camera components along with a description of how each component functions to make the camera work. With the exception of a few hints to help start the disassembly process, student teams approached this task in their own way, probing their observations to the extent they deemed necessary to understand the camera's design.

In the lecture, the design of the Fujifilm QuickSnap Outdoor 1000 camera was presented using a multimedia PowerPoint presentation. The presentation began with a brief history of one-time use cameras and the development process used by Fujifilm. Following this, all components of the camera, starting with the packaging, were identified, and their functions described with the use of one or a combination of the following: animation, computer-aided design (CAD) renditions, and video clips showing the movement of components within the camera and their interconnection with other components. The components were presented in the order one may encounter them if disassembling the camera. Figure 1 shows excerpts of the PowerPoint slides used for the lecture.

Task 3 (Posttest 1)

The third task was the same in both sequences, and it served as the first posttest. Using an instrument administered online, students were asked to respond to three types of questions (i.e., system decomposition, camera doctor and variant design,). The three question types relate to common tasks performed in the engineering design process. All questions were designed to apply the knowledge students were expected to have gained about the camera's part-function relationships from the previous task (DAA activity or lecture). A description of the three question types follows:

- System decomposition refers to the process of dividing a system into smaller parts or subsystems for the purpose of reducing complexity. It occurs in the problem definition phase of the design process to facilitate a better understanding of the problem to be solved. A system can be decomposed based on functions, user actions or key customer needs (Ulrich and Eppinger, 2004). For the system decomposition component a different user or camera action (i.e., aim, shoot, wind, and protect film) was described in each of the four questions. Also included in each question were the pictures of 18 Fujifilm QuickSnap Outdoor 1000 camera components. Students were required to select all the components that function to allow each identified action to occur.

Figure 1. Excerpts from the multimedia PowerPoint presentation used with the lecture.

- Troubleshooting is the common engineering task that students were asked to perform with the Camera Doctor questions. It is a form of problem solving that is applied to the repair of failed products or processes, and is very prevalent in the testing phase of the design process. Troubleshooting requires an integrated understanding of how the system being troubleshot works (Jonassen, 2000). For the camera doctor component, examples of photographs taken with cameras with different defects were presented in each of the four questions. Table 2 shows examples of the photographs that were used in the questions. Also, included in each question were the pictures of 18 Fujifilm QuickSnap Outdoor 1000 camera components. Students were required to diagnose the defect that would have led to the poor photograph by choosing the malfunctioned user or camera action (aim, shoot, wind, or protect film), selecting the components that may be defective from the 18 components presented, and describing what may have gone wrong in terms of the camera's functionality.
- Variant design is one classification of engineering design. It involves varying the parameters of certain aspects of a product to develop a new and more robust design (Otto & Wood, 2001). Variant design techniques are used to create scaled product variations for a product line. For the variant design component two scenarios were presented, each describing a need for new

Pictures	Description
	The picture has a dark rounded spot in the top left hand corner. The image progressively fades and becomes more blurred towards the bottom right hand corner.
	The picture below has discolored streaks along the sides.

Table 2. Examples of the photographs used in the camera doctor questions.

camera functionality (i.e., three different shutter speeds and a viewfinder that can be used to see any object blocking the lens). Students were asked to describe how the original design of the camera could be modified to achieve the new functionality.

Task 4

The fourth task was either the lecture (Sequence 1) or the DAA activity (Sequence 2), a reversal of task 2 such that all participants would experience both instructional methods.

Task 5 (Posttest 2)

The fifth task was the same in both sequences, and it served as the second posttest. For this task students were presented with images of 18 Fujifilm QuickSnap Outdoor 1000 camera components and asked to select from this group all the components that function to prevent the superimposing of images (i.e., multiple pictures being captured on the same film frame). This task, like task 3, was designed to apply the knowledge students were expected to have gained about the camera's part-function relationships. Following both instructional tasks, this assessment allowed the effect of different task sequences to be evaluated.

Post Lab Survey

Following task 5, students completed a post lab survey. Students responded to questions about their background and perception of both instructional tasks. Using the seven-point Likert-type scale used in the previous study (Dalrymple et al., 2011), students rated both the DAA activity and lecture on: 1) perceived sense of learning, 2) enjoyment derived from engaging in the activity, and 3) helpfulness in preparing them to respond to the questions in task 3. The three aforementioned elements were used to measure the motivation elicited from each instructional approach. Students also rated their prior experience disassembling objects using a seven-point scale that ranged from (1) no experience to (7) extensive experience. To further measure the motivation specifically elicited by the DAA activity, 30 questions from the Intrinsic Motivation Inventory (IMI) were used to capture students' interest, perceived competence, effort, value and pressure experienced while engaging in the DAA activity. The IMI is a multidimensional measurement device designed to assess participants' subjective experience related to a target activity (Deci, Eghrari, Patrick, & Leone, 1994; Ryan, 1982).

ANALYSIS

The unit of analysis was the individual. The pretest, posttest 1, posttest 2, and post lab survey were scored and analyzed for each student to:

- Measure and compare the frequency of students that transferred knowledge from the DAA activity and lecture.
- Measure and compare students' reported sense of learning, enjoyment, and perception of helpfulness (elements of motivation) for the DAA activity and lecture.
- Measure students' interest, perceived competence, effort, value and pressure experienced (IMI measures) while engaging in the DAA activity.
- Identify demographic, background, and motivation measures that may potentially mediate the transfer of knowledge from the DAA task.

To established reliability of scoring on open-ended questions in posttest 1, a randomly selected subset, consisting of 15% of the responses to variant design and camera doctor questions were independently scored by two researches. A minimum of 90% consensus was attained on both question types. All other questions were scored using a developed Microsoft Excel formula that was applied to all responses in the sample. Details of the scoring and analysis procedures used for each assessment instrument are provided in the following sections.

Pretest

Responses to the pretest were evaluated to determine students' prior knowledge of the part-function relationships of the Fujifilm single-use camera. Students were asked to select the components that matched the identified function descriptions. Every correct part-function match was awarded one point. The maximum score attainable for the pretest was eight. The average pretest score of students in each sequence, i.e., DAA First or Lecture First, was statistically compared to test for condition comparability at the start of the lab. It was expected that all student will show little prior knowledge of the camera's part-function relationships.

Posttest 1

The three types of questions used in posttest 1 were expected to illuminate the differences in the two instructional approaches (DAA activity and lecture) in terms of learning. Both instructional approaches were expected to have equivalent outcomes on the system decomposition questions which mainly required students to recall information about the functions of the camera's parts. The DAA activity, however, was expected to show advantages over the lecture on the variant design and camera doctor questions, which required the knowledge of the function and interconnectedness of the parts to be recalled, adapted and applied to novel problems. To test these hypotheses the average scores of students in the DAA First and Lecture First conditions were compared for each question type.

The system decomposition questions asked students to identify all the components, from a selection of 18, that function to allow each described action to occur. Students were awarded a point for each correct component selected and each incorrect component that was not selected. No points were awarded for selecting or not selecting components that do not have a primary contribution to the identified action. To ensure a maximum attainable score of 1, a point was valued at $\frac{1}{(18 - NPC)}$, where NPC is the number of components that do not have a primary contribution to the identified action. An example of this scoring method is presented in Table 3.

For the camera doctor questions, students were required to diagnose what part-function failures would cause each defective photograph at three levels of specificity by: 1) choosing the malfunctioned user or camera action; 2) selecting possible components, associated to the malfunctioned user or camera action, that may be defective; and 3) identifying the main defective component and describing how it may have malfunctioned. For each correctly identified user or camera action, a score of 1 was assigned, otherwise the score was 0. The selection of possible defective components was scored in the same way as the system decomposition questions. With respect to the descriptions of how the main component malfunctioned, answers that identified the correct primary mechanism with defects received a score of 1 and those that did not received a score of 0. The description component of three of the camera doctor questions was scored. The description component of the fourth question was omitted since the presented scenario could have been caused by multiple primary components with defects and a reliable scoring method could not be achieved. Examples of scored responses that described how the main component malfunctioned are presented in Table 4.

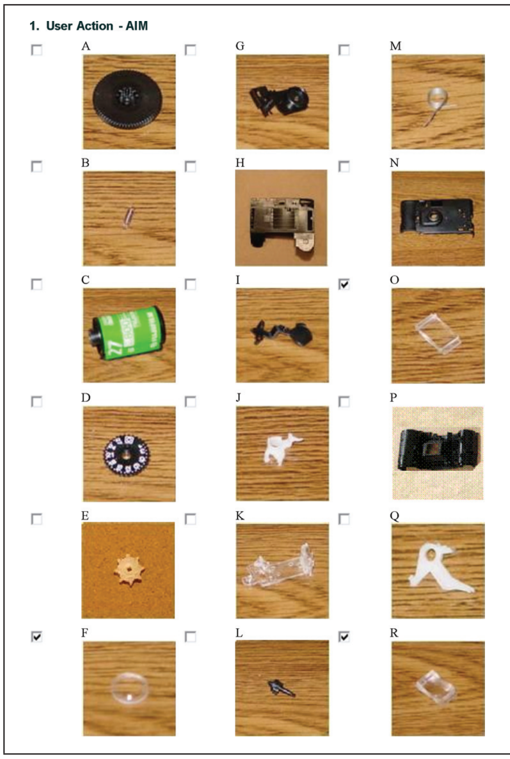
	Components labeled **F**, **O** and **R** have a primary contribution to the Aim action. For identifying these components 3 points are received (one point each). Components **A**, **B**, **C**, **D**, **E**, **H**, **I**, **J**, **L**, **M**, **N**, **P**, and **Q** do not relate to the Aim action and 13 points are received for not identifying these components (one point each). Component G is interconnected with F, and component K is interconnected with components O and R, however G, and K do not have a primary contribution to the Aim action. No points are awarded for not selecting them. Total points received = 16 $1 \text{ point} = \frac{1}{18 - NPC} = \frac{1}{18-2} = \frac{1}{16}$ $\text{Total Score} = 16 \times \frac{1}{16} = 1$

Table 3. Scoring method for system decompositions questions.

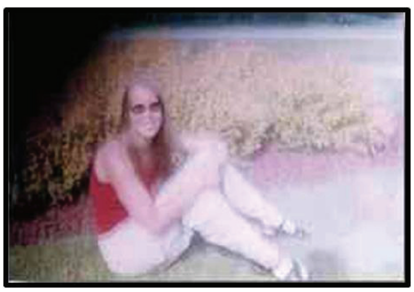
Photo	Response	Scoring Rationale	Score
 The picture has a dark rounded spot in the top left hand corner. The image progressively fades and becomes more blurred towards the bottom right hand corner.	The **shutter**'s spring may have been worn down and not pulled the **shutter** back smoothly, or the **shutters** parts may have caught and not opened and closed smoothly.	The correct primary mechanism with defects is identified.	1
	Film was exposed to too much light on one side and not enough on the other. It most likely wasn't flat against the inside.	The correct primary mechanism with defects is **not** identified.	0

Table 4. Example of scored responses to the camera doctor questions.

For the variant design questions students were asked to describe how the original design of the camera can be modified to achieve: 1) three different shutter speeds and 2) a viewfinder that can be used to see any object blocking the lens. A reasonable approach for achieving three different shutter speeds includes a modification to the extension spring system. Descriptions that included a modification to the spring system received a score of 1, and those that did not received a score of 0. To make it possible for the viewfinder to be used to see any objects blocking the lens the rays of light entering the lens must be directed to the viewfinder. Figure 2 shows the implementation of the viewfinder and lens in the design of the Fujifilm single-use camera. Descriptions that described an appropriate mechanism such as a mirror or prism for accomplishing this received a score of 1. Descriptions that indicated the need for a mechanism to direct the rays of light entering the lens to the viewfinder, without identifying the mechanism received a score of ⅔. Descriptions that suggested the lens and viewfinder should be superimposed received a score of ⅓ (although this answer alludes to the fact that rays of light entering the lens should also enter the viewfinder, this solution is infeasible). Descriptions that did not mention or suggest that the lens and viewfinder need to be interconnected received a score of 0. Examples of scored responses to the variant design questions are presented in Table 5.

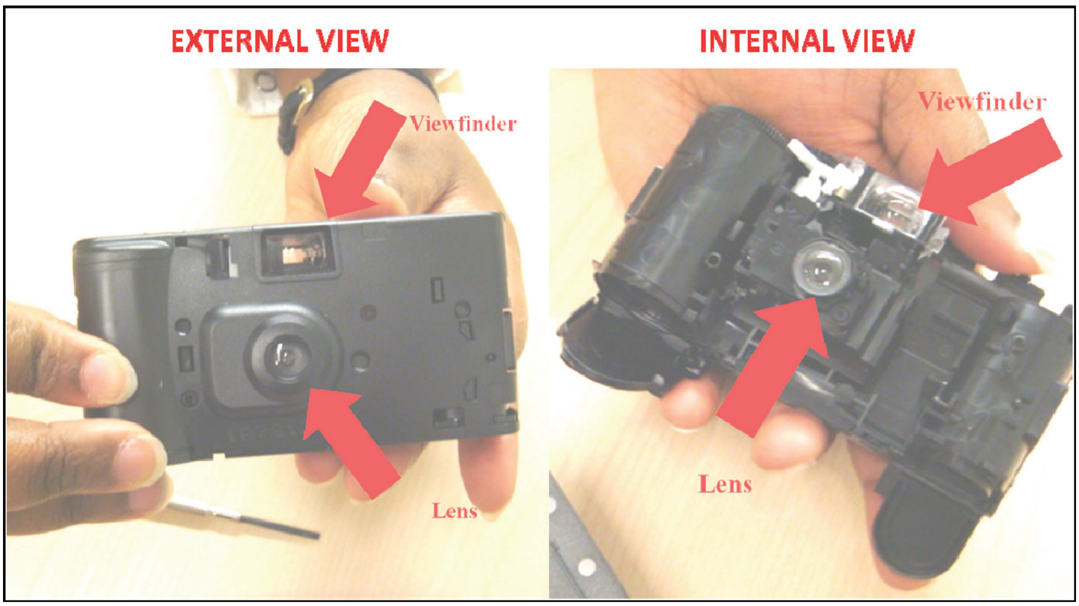


Figure 2. Viewfinder and lens in Fujifilm QuickSnap Outdoor 1000.

Response	Scoring Rationale	Score
Add a selection knob to select the tension on the shutter spring. Set three different shutter spring tensions so you will have three different speeds.	Spring system is modified	1.00
I will vary the original design by creating a mechanism to change the shutter speed. This will consist of a shutter that can be adjusted and therefore, changes the speed.	No modification of spring mechanism	0.00
I would use a series of mirrors to prevent any finger shots. Mirrors will be used to redirect the line of sight for the user. So instead of looking out of a viewer, the user can see exactly what will be showing up in the lens.	Mechanism identified to link rays entering lens to viewfinder	1.00
After the light passes the lens, but before the shutter, there would need to be a device to send an image up to the viewfinder. It couldn't be after the shutter or the only time an image would appear in the viewfinder is when a picture was taken.	No mechanism identified to link rays entering lens to viewfinder	0.67
I will make the lens that user look through [viewfinder] to be right above or even on the camera lens where you take pictures. Then the objects that you see through will be the pictures of the objects you are taking.	Suggests lens and viewfinder should be superimposed	0.33
You need to make the viewfinder bigger.	No indication of the interconnectedness of the lens and viewfinder	0.00

Table 5. Examples of scored responses to the variant design questions.

Posttest 2

Students were presented with images of 18 Fujifilm QuickSnap Outdoor 1000 camera components and asked to select from this group all the components that function to prevent the superimposing of images. This task was scored in the same way as the system decomposition questions. The average score of students in the DAA First and Lecture First situations were compared to test for condition equivalency at the end of the lab.

Post Lab Survey

To establish the goodness of the motivation measures used (students' perceived sense of learning, enjoyment derived from engaging in the activity, and helpfulness in preparing them to respond to the posttest 1), the interitem consistency reliability was measured by calculating the Cronbach's alpha for motivation elicited by the DAA activity and lecture. In addition, convergent validity was tested by correlating the ratings obtained for the DAA activity using the motivation measures with the subscale scores from the IMI.

It was expected that students would find the DAA activity more motivating than the lecture, and to test this hypothesis the mean rating for each element of the motivation measure was calculated for each instructional task and statistically compared. Using the appropriate statistical tests, students' responses to posttest 1 were further analyzed to determine if gender, prior experience disassembling objects, and motivation had any effect on the outcome.

RESULTS

A statistical significance level of $\alpha = .05$ was set for all statistical tests, and results of tests described as significant have a p value that meets this criterion. Statistical tests were conducted using the SPSS 16.0 for Windows (November 15, 2007) computer package.

Motivation

The three measures of motivation, i.e., perceived sense of learning, enjoyment derived from engaging in the activity, and helpfulness in preparing students to respond to posttest 1, were found to have an acceptable interitem consistency. The Cronbach's alpha reliability coefficient for the measure of motivation elicited from the lecture and DAA activity are .775 and .780, respectively.

To test for convergent validity, the previously identified measures for motivation elicited by the DAA activity were correlated with the subscale scores of the Intrinsic Motivation Inventory (IMI), which was also used to assess participants' subjective experience related to the DAA activity. The enjoyment element from the motivation measure ($M \pm SD = 5.87 \pm 1.18$) and interest from the IMI (5.20 ± 1.23) were significantly correlated, $r\,(325) = 0.676$, $p < .001$. There was also a strong significant correlation of value from the IMI (4.86 ± 1.23) as was the case for both the learning element from the motivation measure (5.30 ± 1.24), $r\,(325) = 0.602$, $p < 0.001$ and the helpfulness element from the motivation measure (5.15 ± 1.22), $r\,(325) = 0.545$, $p < 0.001$.

Using the paired samples t-test on each element of the motivation measure, the mean ratings for the DAA task were found to be significantly higher than the mean ratings for the lecture, as illustrated in Figure 3. On students' perceived sense of learning which ranged from nothing (1) to a lot (7), the mean rating for the DAA task was 5.30 ± 1.24 ($M \pm SD$), and for the lecture task, it was 4.84 ± 1.26, $t\,(324) = 7.580$, $p < .001$. On enjoyment derived from engaging in the activity which ranged from strongly disliked (1) to strongly liked (7), the mean rating for the DAA task was 5.87 ± 1.18, and for the lecture, it was 5.23 ± 1.31, $t\,(324) = 10.641$, $p < .001$. On helpfulness in preparing students to respond to the variant design question in task 5 which ranged from not helpful (1) to very helpful (7), the mean rating for the DAA task was 5.15 ± 1.22 and for the lecture

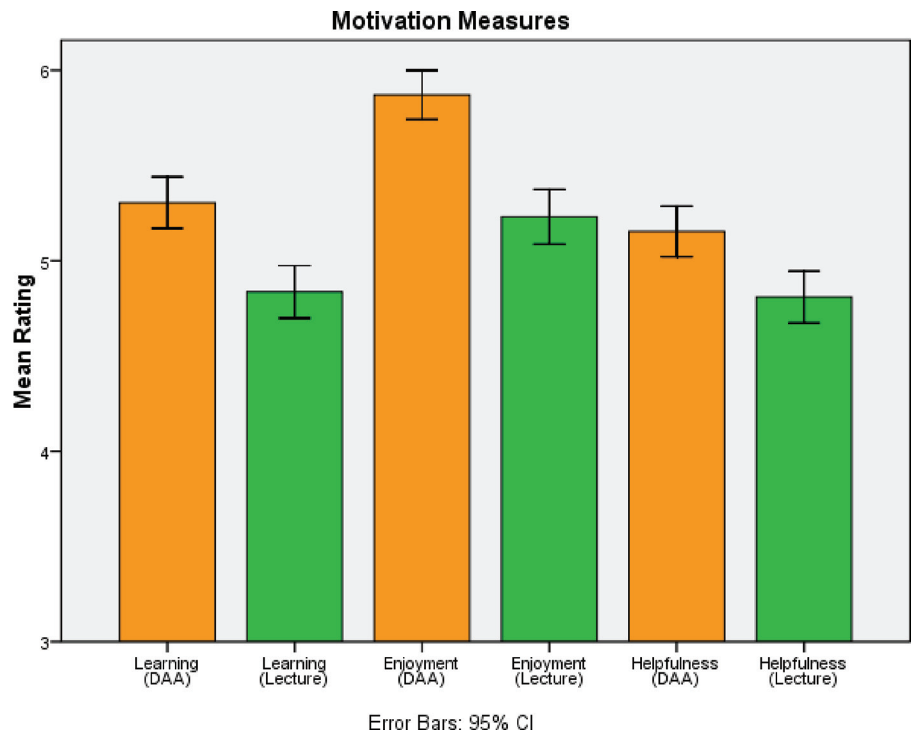


Figure 3. Motivation measures.

it was 4.81 ± 1.25, t (324) = 5.263, p < .001. The motivation measures were further supported by the comments students provided on the post lab survey. Of the 57 students that provided comments related to the lab, 86% referred to satisfaction or enjoyment. Table 6 shows a sample of these responses.

Learning

Task 1 (Pretest)

Out of a possible eight points, the mean pretest score for students in the DAA First sequence was 1.01 3 .952 (*M* 3 *SD*), and, for students in the Lecture First sequence, it was 1.28 3 1.14. The results of the independent t-test, indicate a significant difference in the mean pretest scores of the two sequences with students in the Lecture First sequence having an advantage, with respect to prior knowledge of the content, to students in the DAA First sequence, t (314) = -2.26 (equal variances not assumed), p = 0.024. The results of the pretest, however, indicate an overall low prior knowledge of the design of the Fujifilm single-use camera, and if either condition started with an advantage in prior knowledge, it was the control condition (Lecture First).

Comments
• This activity was great and I didn't fall asleep for the first time in a 126 class
• If this is engineering, I love engineering!!!
• I liked this lab a lot; it was nice to be exposed to another aspect of engineering. Not just staring at a computer and plugging in functions and numbers.
• I think this was a good activity to learn about the importance of reverse engineering.
• This class teaches me important engineering skills.
• I found this activity intriguing. I would like to do more activities like this.
• This presentation was different and had a new learning experience.
• Good Program. Would like to see programs like these more often in lab.
• I liked this lab more than the other labs.
• Great activity, I am now again considering ME.
• I had a great deal of fun. I felt that the presenter did a very good job and these presentations have impacted me in a very positive way.
• This was a good activity to do because many people have no experience in this sort of experiment
• I liked taking the camera apart cause I felt that I had a better understanding of what everything did
• Reverse Engineering is a good key to learning...
• I love reverse engineering, it makes learning a lot easier.
• It's the most amazing class where we can get a feel of what actually engineering is.
• This was an amazing lab. I would hope that all labs could be similar to this, instead of doing activities we don't really need in real life.
• This was a fun lab and I learned a lot about the functions of cameras.
• This is the most interesting lab yet! It was hands-on, and therefore much more interactive and interesting.
• I liked this activity because we, as freshman, are searching for hands-on classes, but what we find are classes that require reading and tests, not so much tangible stuff. This was a great relief from that monotony

Table 6. Additional comments from students.

For task 2, students in the DAA First sequence systematically disassembled the Fujifilm QuickSnap Outdoor 1000 cameras while students in the Lecture First sequence viewed a presentation on the design of the same camera. These tasks were expected to produce different types of learning which students were expected to demonstrate in their responses to the different posttest 1 questions, i.e., system decomposition, variant design and camera doctor.

Task 3 (Posttest 1 – System Decomposition)

The Cronbach's alpha reliability coefficient of the 4-question measure of system decomposition ability was .544. We suspect that this measure showed low internal consistency at least in part because students appeared to interpret the notion of part-function relationships differently. Some students appeared to use a narrower definition (only the most immediately critical parts matter for the function) while others appeared to use a broader definition (parts that support critical parts should be counted). Each of these questions asked students to identify all the components, from a selection of 18, that function to allow the described action to occur. The maximum possible score was 4. An independent t-test revealed that students who did the DAA activity scored significantly higher on these questions than the students who had the lecture, $t\,(315) = 3.09$ (equal variances not assumed), $p = 0.002$ ($M \pm SD = 3.19 \pm 0.31$ and 3.09 ± 0.27 for DAA First and Lecture First respectively).

Task 3 (Posttest 1 – Camera Doctor)

The Cronbach's alpha reliability coefficient of the 4-question measure of camera doctor (defect diagnosis) is .551. Again, this low internal consistency on these items suggests that these results should be interpreted with caution. For each question students were required to do three things: pick one of four user or camera actions that would cause each flawed photograph, select the components of the camera associated with the user or camera action that may be defective and provide a written description of how the main defective mechanism is most likely responsible for the camera's poor functionality. Using the aggregate of the scores from all the components of each of these questions, the independent t-test revealed that there was no difference in performance between the students in the DAA First sequence and the students in the Lecture First sequence, $t\,(323) = .538$, $p = .591$ ($M \pm SD = 6.07 \pm 1.78$ and 5.97 ± 1.73 for DAA First and Lecture First, respectively).

Each of the three camera questions increased in degree of specificity from first picking the camera function, to then selecting relevant parts, to finally identifying and explaining how the critical mechanism malfunctioned and resulted in the poor quality of the photo. This third part of the camera doctor question, was expected to be most sensitive to students' understanding of specific part-function relationships. Thus, a separate post-hoc analysis was conducted on just these scores. The independent t-test revealed that students in the DAA First sequence performed significantly better on these questions than students in the Lecture First sequence, $t\,(323) = 2.026$, $p = .044$ ($M \pm SD = 1.26 \pm 0.90$ and 1.06 ± 0.87 for DAA First and Lecture First, respectively). The highest possible aggregate score is 3. Figure 4 shows a comparison by condition on this measure.

Task 3 (Posttest 1 – Variant Design)

The two variant design questions asked students to describe how the original design of the camera can be modified to achieve a new functionality. For the first question the new functionality was three different shutter speeds. Possible scores for this question were either 1 for responses that described a modification to the spring system, or 0 for responses that did not. Among the 162 students that did the DAA activity first, 110 received a score of 1. Among the 163 students that had the lecture first, 49 received a score of 1. Based on the results of the Pearson's chi-square test, students in the DAA First sequence performed significantly better on this question than students in the Lecture First sequence, $\chi^2\,(1, N = 325) = 46.557$, $p < .001$.

Given that the system decomposition questions preceded the variant design questions, further analysis attempting to control for prior knowledge was possible. Students who noticed that the

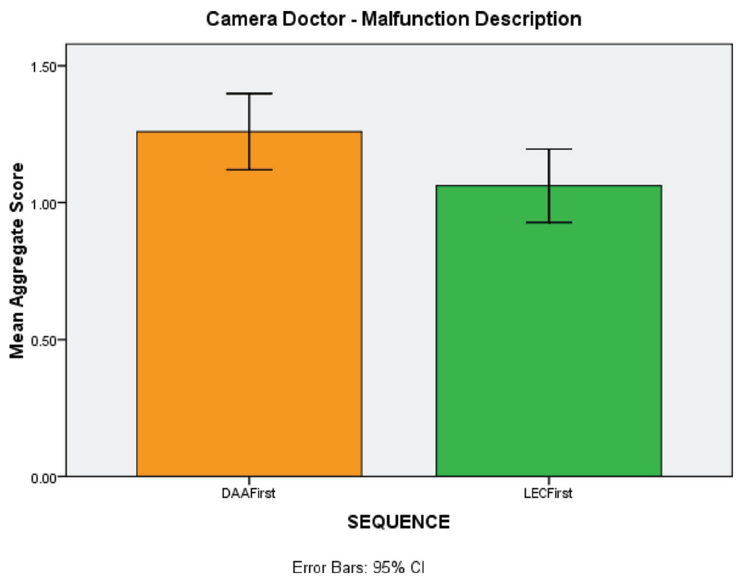


Figure 4. Camera doctor: comparison on the description of the primary defective component.

spring was involved in taking a picture (i.e., got credit for that component in the system decomposition question), had relevant prior knowledge for adapting the spring mechanism in the variant design question about adding variable shutter speeds. More students who did the DAA activity first (DAA students) noticed the spring feature in the system decomposition question than students who had the lecture first (Lecture students), χ^2 (1, $N = 325$) = 17.319, $p < .001$. Examining only the 101 DAA students and the 64 Lecture students who showed the relevant prior knowledge of the spring mechanism, DAA students still showed significantly more transfer to the variant design task that required adapting the spring mechanism, $\chi^2(1, N = 165) = 25.224$, $p < .001$. This suggests that DAA activity was significantly better at helping students adapt their prior knowledge to solve a new design problem, even after attempting to control for relevant prior knowledge.

In the second variant design question, the new functionality was a viewfinder that can be used to see any object blocking the lens. Possible scores for this question were either 1 for responses that identified an appropriate mechanism for directing the rays of light entering the lens to the viewfinder, $^2/_3$ for responses that indicated that a mechanism is required to direct the rays of light entering the lens to the viewfinder, without identifying the mechanism, $^1/_3$ for responses that suggest the lens and viewfinder should be superimposed, and 0 for responses that do not mention or suggest the interconnectedness of the lens and viewfinder. Among the 162 students that did the DAA activity first, the average score (± *SD*) is .504 ± .480. Among the 163 students that had the lecture first, the

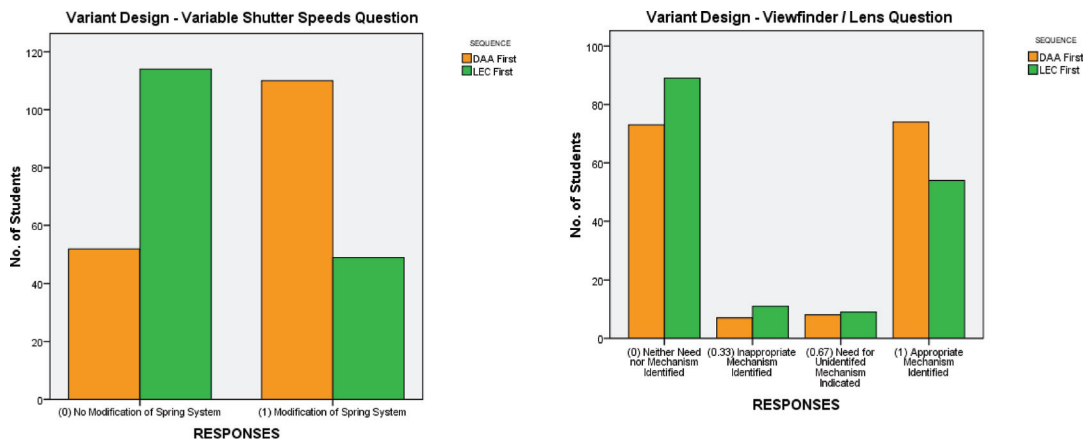


Figure 5. Distribution of scores for the variant design questions.

average score (± *SD*) is .391 ± .460. Based on the results of the Mann-Whitney *U* test, students in the DAA First sequence performed significantly better on this question than students in the Lecture First sequence, ($U = 11596.000$, $n_1 = 162$, $n_2 = 163$, $p = .036$ two-tailed). Figure 5 shows the distribution of scores for both variant design questions, and Figure 6 shows the relationship between prior relevant part-function knowledge and the adaptation of that knowledge in the variant design question.

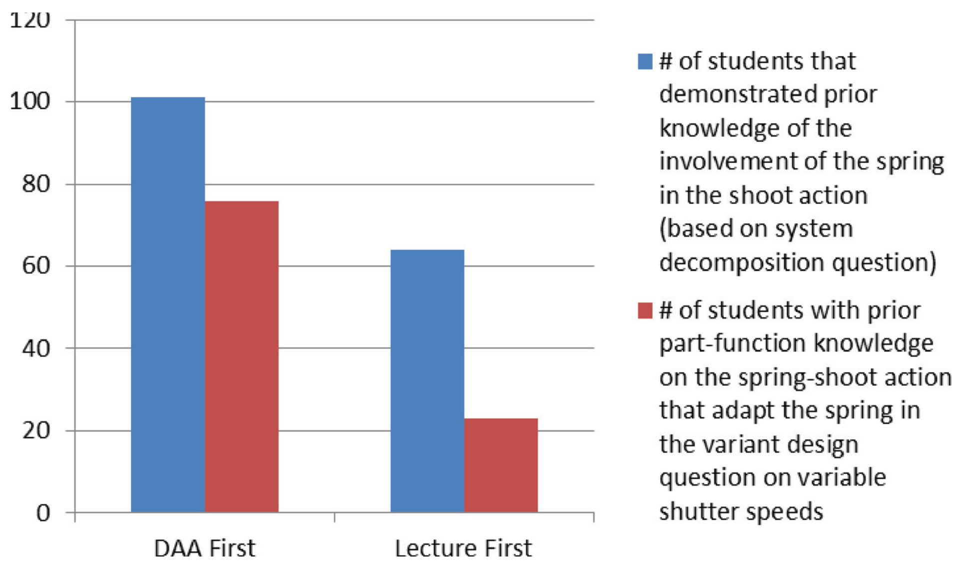


Figure 6. Relationship between prior relevant part-function knowledge and the adaptation of that knowledge in the variant design question.

Task 5 (Posttest 2)

The posttest 2 question asked students to choose from a selection of 18, all the components that function to prevent the superimposing of images. Scores for this question could range between 0 and 1. Based on the results of the independent t-test, there was no significant difference in the performance of students in the DAA First and Lecture First sequence, t (323) = .341, p = 0.733 ($M \pm SD$ = 0.81 ± 0.13 and 0.80 ± 0.11 for DAA First and Lecture First respectively). These results establish condition comparability at the end of the lab.

Effect of Gender, Prior Disassembly Experience, and Motivation

Secondary analyses focused on testing for potential relationships among gender, prior disassembling experience and motivation, as well as potential relationships between students' ability to transfer knowledge from the DAA task, which was evident in the posttest 1 responses of students in the DAA First sequence and any of the demographic, background, and motivation measures collected in the post lab survey. A relationship was found between gender and prior disassembling experience and gender and perceived competence on the DAA activity. On a seven-point scale that ranged from 1 (no experience) to 7 (extensive experience), the average prior experience reported by men was 4.49 ± 1.68 ($M \pm SD$), and for women it was 2.78 ± 1.63. The results of the t-test indicate that this difference is significant, t (323) = 7.46, p < .001. On a similar scale the average competence reported by men (± SD) was 5.21 ± .923, and for women (± SD) it was 4.78 ± 1.09. The results of the t-test indicate that this difference is also significant, t (92) = 2.93 (equal variances not assumed), p = 0.004. Prior disassembling experience (M 3 SD = 4.14 ± 1.81) and perceived competence on the DAA activity (5.12 ± .974) are significantly correlated, r (325) = 0.362, r^2 = .131, p < .001. Beyond the aforementioned, no other relationships were found among the variables (gender, prior disassembling experience and motivation) examined, and none of them accounted for any significant variability in posttest 1 responses for students in the DAA First sequence.

DISCUSSION AND CONCLUSION

This study, like the previous experiment conducted by the authors (i.e., Dalrymple et al., 2011), compared a DAA activity to a control in terms of motivation and transfer. In this study the control, a lecture, provided better comparability in terms of learning objectives and transferable content. Both the lecture and the DAA activity were structured to help students learn about the DfE design principles and the part-function relationships embodied in the Fujifilm single-use camera. With the DAA activity, students disassembled the camera and analyzed its components to discover their function and interconnectedness, while the lecture presented similar content with the use of a multimedia PowerPoint presentation (removing the manipulation and discovery aspects of the DAA process). The hypotheses remained somewhat consistent, particularly given the experimental findings on the deficiencies of lecture with respect to promotion of thought and inspiring interest in a subject (Bligh, 2000). It was expected that on measures of motivation, the DAA activity would be rated higher than lecture; on measures of learning where the task required students to recall the part-function relationships explored in both instructional approaches, the DAA activity and lecture would look equivalent; and on measures of deeper understanding, where the tasks moved away from recalling part-function relationships and towards diagnosis and redesign, the DAA activity would outperform lecture.

With respect to motivation, the results were consistent with previous findings. Notwithstanding students' high ratings for lecture (5.23, 4.84, and 5.15 on a seven-point scale for enjoyment, learning, and helpfulness, respectively), which were greater than those for both comparative tasks in the previous experiment, the DAA activity proved to be significantly more motivating on all three measures, regardless of the order in which students experienced the activities. The motivation measures continued to produce alpha coefficients greater than 0.75 and showed significant correlations to the peer reviewed Intrinsic Motivation Inventory (IMI); further validating these findings.

Regarding learning, three different posttest 1 questions were used to characterize the potential differences between lecture and the DAA activity. The three question types varied in context, relative to the instructional/initial learning tasks. The system decomposition questions, most closely related to the context of initial learning, tested for students' ability to recall the associations between camera parts and their function. The camera doctor questions asked students to diagnose defects in a camera, based on the analysis of photographs. The question retained some aspects of the part-function association and advertently tested for recall; however it deviated into the realm of novel problem solving, asking students to diagnose the presented symptoms and generate hypotheses about the source of the malfunction (Jonassen, 2000). The variant design question deviated most from the context of initial learning, testing for the greatest distance of transfer. It required students to modify the current camera design to achieve new functionality. Design problems are the most complex and ill-structured kinds of problems (Jonassen, 2000).

The results showed that the DAA activity had advantages over lecture in terms of recall and transfer. Students who did the DAA activity scored higher than those who had the lecture on the system decomposition and variant design questions. On the camera doctor questions there initially appeared to be no difference; however, once the component-function part of the question was removed from the analysis, the DAA activity showed advantages over the lecture. Students that did the DAA activity were better able to generate plausible hypotheses about the reason for the malfunction. It is important to note that the DAA activity lead to greater transfer as observed in the initial study, without the added cost of additional instruction or worse basic understanding. It is also impressive that students with one exposure to one camera were able to notice and adapt its features to develop a new design and diagnose defects in a camera after viewing flawed photographs. In other literature on transfer, it often takes multiple examples or cases for students to develop a working schema (Gick & Holyoak, 1983) or show adaptive expertise (Sears, 2006). In this sense, being able to adapt knowledge after one exposure is impressive and reveals a potential key advantage of the DAA process (iteration of observation and follow-up probing).

The learning and transfer observed from the DAA activity was not impacted by any of the variables measured in the post lab survey. None of the demographic, background, and motivation data accounted for any significant variability in students' ability to learn or transfer knowledge from the DAA activity. Although women reported having significantly less prior disassembling experience than men, similar to the findings of study 1, and a lower perception of their competence on the DAA activity than men, they performed equally to men on measures of learning and transfer.

Both studies conducted by the authors involved a camera, a tangible and predominantly mechanical device, as the artefact under investigation. Would the observed benefits remain true for other types of engineering artefacts? The DAA framework has already begun to show promise at cultivating student's adaptive expertise in engineering, i.e., ability to apply knowledge effectively to novel problems. These early findings push for further examination to test the generalizability of the claims. New types of engineering artefacts, beyond those that are predominantly mechanical and/or, tangible, need to be assessed.

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