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Implementation of a Plan-Do-Check-Act Pedagogy in Industrial Engineering Education*

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This paper explores the impact of introducing a learning-through-application-based teaching method to science and engineering instruction in higher education. The growing gap between traditional teaching approaches and the needs of today's college graduates is addressed by introducing a learning pedagogy based on Deming's Plan-Do-Check-Act (PDCA) cycle. A semester of experimentation with a class of thirty-one students shows that 94% of students experienced a significant increase in learning and 90% have increased confidence in application. Results suggest that, compared to traditional teaching approaches, the proposed method could be a more effective way of teaching science and engineering.

Keywords: Deming Cycle; Shewhart Cycle; PDCA; PDSA; pedagogy; learning; mastery

1. Introduction

The typical academic experience of a college student in science and engineering can generally be summarized as such:

- Students attend classes or labs and the instructor delivers information, typically in a lecture or discussion format.
- Students capture the information by listening, taking notes, and potentially interacting.
- Homework assignments and exams are administered to gauge students' understanding of important concepts.
- Students skim textbooks and notes for "the answer" to homework assignments and to cram information into their brains for exam preparation.
- Students complete homework assignments and exams, which are then graded and returned.
- Much of the information is purged from the students' brains, some information is retained, and the process repeats itself for the next wave of information.

The above process has been the primary mode of operation at colleges and universities since the existence of modern education. Despite calls for more innovative methods of engineering and science instruction, lecture and exams remain the predominant method of instruction and evaluation, respectively [1]. Paradoxically, learning often takes place at the point where a student realizes what he or she does not know. This dynamic creates a gap between the skills developed in education and skills a graduate needs in the workforce [2, 3]. If a critical output of college education is that students truly learn the concepts deemed important by their course of study, shouldn't there be a way to measure learning beyond the point a student finds out, upon receiving a graded assignment or exam, what they do not know? For science and engineering students, the answer to this frustration may lie in one of the foundational fundamentals that permeate through the entirety of their curriculum—the scientific method.

2. Background

2.1 PDCA

The Plan-Do-Check-Act (PDCA) cycle is a learning and improvement cycle that evolved from the broader scientific method [1]. The PDCA cycle is most commonly credited as being created by Dr. W. Edwards Deming, an American engineer, professor, author, and management consultant. However, Deming called it the "Shewhart Cycle" based on his learnings from his mentor Walter A. Shewhart. Other names for the concept include the Deming Cycle and the Deming Wheel. Later in life, Deming began referring to the methodology as the PDSA cycle, replacing "check" with the word "study" to bring clarification to the true intent [4]. For the purposes of this article, the more common terminology—PDCA—will be used. Fig. 1 shows the PDCA cycle with descriptions of each stage.

A key principle of the PDCA cycle is that it promotes learning through iteration; the findings from one cycle generate a new cycle, extending knowledge even further. During Deming's extensive work in Japan in the 1950s, many Japanese companies embraced the cycle as the foundation of their organization's learning culture. Perhaps the most popular advocate of this philosophy is Toyota. A common mantra at Toyota is the notion of "we do

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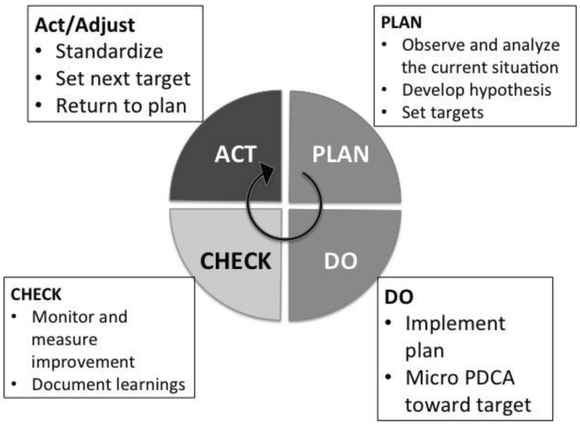

Fig. 1. The PDCA Cycle.

not just build cars, we build people. [5]" This is accomplished by developing every employee at every level to use critical thinking and problem solving. Toyota can be viewed as a community of scientists who continually seek improvement based on the scientific method to advance their operations [6].

The Toyota Production System has gained international notoriety for its tools and methods such as kanban, 5s, and total productive maintenance. However, the organization is adamant that those tools are just ways to accomplish improvements, and the fuel that drives the systematic improvement is indeed the PDCA cycle. The PDCA cycle is so integral to the system that the company utilizes a standard communication format, A3 reporting, to reinforce the PDCA mindset in all aspects of its business [7, 8].

2.2 Teaching in higher education

Interestingly, the aforementioned experience of a typical college student starts out following the PDCA cycle. The instructor develops the "plan" by issuing assignments or by teaching concepts on which students will be tested. The students then "do" by completing the assignments or exams. The "check" is accomplished when the instructor grades the assignment or exam. However, the critical phase that is omitted is the very one that completes the iterative cycle that drives learning—the "act" phase. Once the students find out what they do not know, the current process of teaching doesn't allow them to "act," or adjust, and start the cycle again. The current system is structured on one-way feedback—the instructor grading and informing the student what they do and do not know. Without two-way feedback through which the student can adjust and demonstrate they have closed their knowledge gap, learning is severely crippled. The fundamental idea of iteration (PDCA) is learning. Shoji Shiba, author of *Four Practical Revolutions in Management: Systems for Creating Unique Organizational Capability*, stated "To eschew PDCA is not only arrogant; it is inefficient & often ineffective." [9]

This missing link in the current typical teaching method has not gone unnoticed. *The Teaching-Learning Paradox: A Comparative Analysis of College Teaching Methods*, developed by the Center for the Advanced Study of Educational Administration at the University of Oregon in 1968, called for future research to explore teaching-learning models [10]. Barr and Tagg discussed the need for a shift from an "instruction" paradigm to a "learning paradigm" in their 1995 article *From Teaching to Learning: A New Paradigm for Undergraduate Education* [11]. The persistent question that remains is: How can this be put into practice?

Perhaps the most notable work along the lines of learning in education comes from Benjamin Bloom, author of *Bloom's Taxonomy of Educational Objectives*. Bloom coined the phrases "learning for mastery" and "mastery learning." In mastery learning, Bloom imagined that, in contrast to conventional instruction, individual students would be helped (by the instructor, peers, etc.) to master each learning concept before proceeding to a more advanced learning concept [12]. Putting Bloom's work into action, Eureka! Ranch founder Doug Hall is using a "cycles to mastery" approach, featuring the PDSA[1] cycle, as the primary teaching method for undergraduate minor courses in Innovation Engineering at the University of Maine [13].

There is other minor evidence of the incorporation of the scientific method as a teaching method. Some instructors have assigned A3 reports as a final deliverable on projects, as opposed to more traditional research papers [14]. However, the efforts to transform teaching into learning have largely been incomplete, isolated, and/or not cohesive. This article will discuss one approach that was implemented in an undergraduate Industrial and Systems Engineering course in an attempt to establish a framework for a PDCA pedagogy. In the spirit of practicing what is preached, the approach will be presented in the form of the scientific PDCA method.

Matsuo and Nakahara [15] studied the effects of PDCA on workplace learning. Their results indicated that PDCA had positive effects on workplace learning. According to Chien [16], determining how to enhance learning satisfaction has become an important task for teachers. Carroll et al., [17] used PDCA for self-assessment to improve processes that affected educational learning outcomes.

[1] Innovation Engineering™ uses the phrase PDSA explicitly, thus it was used here as such.

These are examples of using quality tools to impact learning and improve teaching.

3. Presentation of analysis

3.1 The hypotheses of this research

The approach presented in this article was developed and used in an undergraduate work design and operations management systems course in the Industrial and Systems Engineering (ISE) department at the University of Alabama in Huntsville. The course occurred in the fall semester of 2014 and consisted of 31 students. Approximately two-thirds of the students were ISE majors and the remaining third were Mechanical and Aerospace Engineering (MAE) majors taking the course as an elective. The grading for the course would place very little, if any, emphasis on exams and a heavy focus on applied assignments and case studies to be analyzed using the PDCA cycle. The grading method would also follow the PDCA cycle, allowing students to turn assignments in multiple times with revisions based on feedback and learning.

In addition to the PDCA cycle, the assignment format also included a "reflection" section. The idea for adding the reflection section was derived from Kolb's model of experiential learning (shown in Fig. 2). Kolb's model is one of the most widely studied models for adult learning. The experiential learning cycle consists of four stages: abstract conceptualization, active experimentation, concrete experience, and reflective observation [18].

Reflective observation allows the "doer" to pause, step away from the task at hand, review what has been done, and relate to the experience on a personal level. For students, the ability to relate key course concepts to their personal life is important because many of them do not have professional experience to which they can connect key principles.

In applying the PDCA pedagogy as the primary method of teaching this course, the following hypotheses were developed:

- Knowledge retention of the key course concepts will increase.
- Students' confidence in using the tools and techniques from class will increase through repetition.
- Using the PDCA cycle to grade toward mastery and learning will improve a participating student's performance by a full letter grade.

The published literature on the application of PDCA to education is limited, but a couple of applications that were found include Ruey, et. al. [19] and Murphy [20].

3.2 Methodology used to test hypotheses

The delivery of the in-class portion of the course was not significantly different than the way it has been conducted in the past. Each key course concept was covered via lecture, discussion, and a variety of hands-on simulations and activities. However, the way students were graded was altered significantly. Fig. 3 shows a comparison of how the course was graded in the fall of 2013 versus the grading system derived for the new approach. While the categories appear the same in Table 1, the details and formats of each category changed considerably.

The Assignments category refers to assignments that students are responsible for completing outside of class. For both 2013 and 2014, assignments were administered via the University's online course management system. In 2013, a homework assignment or quiz was issued each week. Each assignment was related to that week's in-class material, and was due before the next class (in this case, the course was taught one day per week, thus each assignment was to be completed in one week). Assignments were graded in the traditional manner—the instructor would grade and give feedback after the due date. There were 12 total assignments, allowing students to drop the lowest two scores. Assignments were worth equal weight and made up 25% of the students' total grade.

For 2014, assignments were reformatted to reflect the PDCA learning mindset. Eight assignments were issued, covering the major concepts of the course. In contrast to previous years, these assignments were more intensive and abstract in nature. The majority of the assignments were left open-

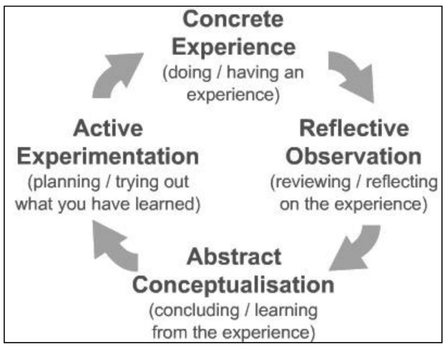

Fig. 2. Kolb's Experiential Learning Cycle.

Table 1. Comparison of Grading Schemes

	Category Weight	
Grade Category	**2013**	**2014**
Assignments	25%	50%
Exams	50%	30%
Case Study Project	25%	20%

Table 2. Assignment examples

ASSIGNMENT 2
Plan: Choose a specific problem you are experiencing (work-related, personal-life related, school-related, anything). Complete the following sections on the Practical Problem Solving Form:
a. Problem Description
b. Problem Analysis
c. Point of Cause & Standardized work check
d. 5-why root cause/therefore analysis
ASSIGNMENT 6
Plan:
a. Pick a process/task at which you consider yourself an expert capable of training someone else b. Prepare to DO a Job Instruction Breakdown Sheet and 4-step training on that process/task

ended, requiring the student to choose a process or situation of their own on which to apply the concepts. There was a new assignment for all non-exam weeks, with the assignment again being related to the most recent class. For some perspective, Table 2 shows sample assignments from the semester.

A standard format for assignment submissions was created containing the following sections:

- PLAN—In this section, the instructor would provide general information on the assignment such as expected deliverables. The student would provide background information on the process or situation on which they chose to perform the assignment, along with a hypothesis or target condition for the process or situation.
- DO—this section is where the student supplies all of the information on what they did to complete the assignment. All supporting material such as process maps, data tables, diagrams and other information was to be attached to the assignment.
- CHECK—in this section, students share their learning based on what they did. Guiding questions included "Did the implementation provide results that you expected in your hypothesis?" and "What unexpected occurrences—both positive and negative—did you experience?"
- ACT—this section required the student to recommend next steps based on what they learned in the check stage. They were to answer either "If the process or situation improved, what needs to be done to standardize and sustain?" or "If the process or situation did not meet target conditions, what should be the next plan?"
- PERSONAL REFLECTION— each assignment ended with students articulating what they personally learned from the assignment. Common thoughts expressed in this section included most valuable things gained from the assignment, what would be done differently if the assignment were to be performed again, and how the concept could be leveraged to the students' everyday life.

Under the new course format, students were required to complete each assignment and were not allowed to drop the lowest grade(s). However, each assignment was given a 3-week due date and students could turn the assignment in as many times as desired. After each submission, the instructor would grade, provide feedback, and students were allowed to adjust accordingly. In Bloom's terms, the instructor and the student were working toward mastery together. Each student's grade for their final submission was the only grade counted. Each assignment was weighted equally and accounted for 50% of the total grade for the course.

In the fall semester of 2013, exams were administered in the traditional manner. There was a midterm and a final exam. Each exam consisted of 30–50 questions made up of a mix of multiple choice, short answer, calculations, and essay questions. The exams were graded by the instructor and provided to the student for review. Each exam was weighted equally, and made up 50% of the students' total grade.

In 2014, under the new PDCA pedagogy, there were no traditional exams. Instead, the "exam" days in class were used in various ways as progress checkpoints for the course. There were three "exams" that were spaced out equally throughout the semester. Each exam was worth 10% of the overall grade. The exams were designed to be stress-free yet provoke deep thought and true reflection. The exams consisted of:

- Exam 1—Students provided an analysis of the first third of the semester. The requirement was a written reflection to be turned in; guiding questions were provided relative to most valuable concept, concept that still needed clarification, and thoughts on the PDCA assignment format. Class time was spent with the instructor sharing his learning from the first third of the semester, and open discussion with students providing feedback and suggestions on the course thus far.
- Exam 2—Two-thirds of the way through the semester, there was noticeable improvement of the students' understanding and use of the PDCA mindset. Exam 2 asked the students to research and analyze two articles of their choice, given the topics were related to topics covered in the course. The deliverable from the student was a summary of the articles, analysis of what was found to be the most useful concept covered in the articles, examples of how that concept could be leveraged

to the student's everyday life, and a personal reflection on the semester to that point.

- Exam 3—Exam 3 was the course's "final exam." Based on comments and suggestions throughout the semester, the instructor himself used PDCA and adjusted the plan based on student feedback. Given the nature of the course, arrangements were made to visit a local manufacturing facility. The students were treated to a tour of the facility and a presentation from the company's top management. For the deliverable from the student, each performed an assessment of the operations noting evidence of concepts covered in the course and areas where concepts were not present but could be recommended. Again, the students were also asked to provide a personal reflection on the course as part of the final exam.

The case study assignment for this course is a term project with the option for students to work alone or in pairs. The final deliverable is a completed A3 report detailing an implemented tool or technique from the course to improve an operation of their choice. An A3 report, as mentioned previously, is a standard communication medium used at Toyota and other organizations to present information concisely and visually while also reinforcing the PDCA cycle. A3 is the international paper size that is equivalent to a U.S. 11″ x 17″ page. The A3 report has been used for several years in this course as the format for the case study deliverable. The A3 format forces the students to be able to articulate and defend what was done on the project, as opposed to simply burying the information and data throughout a 20-page term paper. Fig. 3 shows the standard A3 template used for the case study project.

While the format of the case study project did not change from previous years (including the comparative year of 2013), the grading methodology changed considerably. In the past, the case study projects were turned in on A3 reports, but were graded in the traditional one-way feedback manner. The projects were due at the end of the semester, and were then graded upon completion. In 2014, the case study A3 report was due in four phases throughout the semester. Each phase was graded in the same manner as the PDCA homework assignments, as discussed previously. This allowed the problem solver and author of the A3 report (the student) and the mentor (the instructor) to provide two-way communication throughout the project, as this is the way PDCA and A3 learning was intended to function [21].

3.3 Results

The semester of experimentation, fall 2014, had 12 total assignments (8 homework, 4 case study) for which the students could utilize the PDCA grading format. Interestingly, although the students received the idea of such a concept positively, the traditional student mindset of turning assignments in right at the due date continued to be the norm. For the purpose of this study, a student's assignment submission needed to meet two requirements to be fall into the group defined as utilizing the PDCA format: (1) the assignment must have been turned in before the designated cut-off date for feedback, and (2) the assignment must have been submitted multiple times utilizing the feedback given. Overall, only 35% of all assignments met the criteria of utilizing the new PDCA format as it was intended. Table 3 shows the summary of

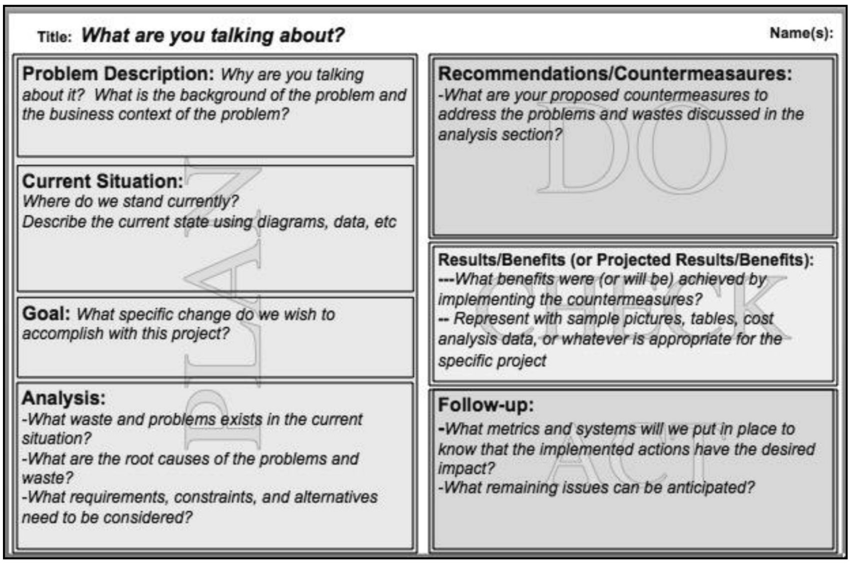

Fig. 3. A3 Report Template.

Table 3. Summary of Submissions

	Yes	No
Assignment 1	17	14
Assignment 2	15	16
Assignment 3	13	18
Assignment 4	14	17
Assignment 5	10	21
Assignment 6	8	23
Assignment 7	9	22
Assignment 8	10	21
Case study I	13	18
Case study II	10	20
Case study III	5	26
Case study IV	8	23
% Yes	**35.5%**	

assignments that took advantage of the PDCA format.

3.3.1 *Analysis of t-tests.*

To determine if there was a significant increase in level of performance on assignments that utilized the PDCA grading format, a series of two-sample t-tests were conducted. For each assignment and case study submission, a null hypothesis (H_0) that the mean of those who utilized the PDCA option ("yes" group) was equal to the group who did not ("no" group) was proposed. Thus, a rejection of H_0 would suggest there is a significant difference in the level of performance of the two groups. An alpha level of 0.05 was used for this study, and the data was analyzed with the statistical software SPSS. It is worth noting that SPSS automatically adjusts the t-test to compensate for unequal sample sizes and unequal variances between the groups, if either or both were the case.

Table 4 shows a summary of the t-test results for each assignment or case study submission.

As shown in Fig. 8, nine of the 12 assignments show a significant difference in the grades of the group who utilized the PDCA option versus the group who did not. Of further note, the three assignments that failed to reject the null hypothesis were the only three assignments of the semester that were "awareness" assignments rather than technical assignments. These assignments were thought-based and involved research and opinion, thus virtually every submission received full credit. The only submissions for these three assignments that did not receive full credit were the very few that were penalized for being late. All 9 of the other assignments involved actual application of concepts from the course.

3.3.2 *Analysis of post-semester survey*

While the hypothesis of improved performance was measurable, the other two hypotheses—increase in retained learnings and increase in confidence in application of the concepts—were more subjective by nature. To gain some insight on these hypotheses, a short survey was created and sent out to all 31 members of the class. The survey was sent out one month after the conclusion of the semester and consisted of three statements:

1. The PDCA assignment format for ISE 324 allowed me to retain learning (key concepts and tools) more effectively than traditional formats.
2. The PDCA assignment format increased my confidence in the application of the concepts and tools more effectively than more traditional formats.
3. Experience gained from the PDCA format of the class will (or has) significantly benefit my engineering career.

Table 4. Summary of t-Tests

	Yes Mean	No Mean	Delta	p value	Ho Decision
Assignment 1	96.12	81.93	14.19	0.02	**reject Ho**
Assignment 2	98.07	87.88	10.19	0.00	**reject Ho**
Assignment 3	100.00	83.22	16.78	0.00	**reject Ho**
Assignment 4	100.00	97.94	2.06	0.20	**do not reject**
Assignment 5	100.00	89.76	10.24	0.01	**reject Ho**
Assignment 6	99.38	84.26	15.11	0.04	**reject Ho**
Assignment 7	100.00	94.09	5.91	0.21	**do not reject**
Assignment 8	100.00	98.10	1.90	0.33	**do not reject**
Case study I	90.78	83.71	7.07	0.03	**reject Ho**
Case study II	97.14	88.84	8.30	0.03	**reject Ho**
Case study III	89.14	83.06	6.08	0.05	**reject Ho**
Case study IV	100.00	93.04	6.96	0.03	**reject Ho**
Overall Means	**97.55**	**88.82**	**8.73**		
Delta omitting 4, 7, &9			**10.5**		

Table 5. Summary of Survey Results

	Question 1		Question 2		Question 3	
Score	# responses		# responses		# responses	
5	15	83%	13	72%	10	56%
4	2	11%	3	17%	6	33%
3	0	0%	1	6%	1	6%
2	0	0%	0	0%	0	0%
1	1	6%	1	6%	1	6%
% max score		**93.3%**		**90.0%**		**86.7%**
Overall Composite Score						**90%**

The survey used a 5-point scale, where 5 = "absolutely agree", 4 = "somewhat agree", 3 = "neutral", 2 = "somewhat disagree", and 1 = "absolutely disagree". Of the 31 students, 18 completed the survey (a 58% response rate). Table 5 shows a summary of the survey results.

4. Discussion of results

Based on the results of the t-tests, it can be concluded that, with over 95% confidence, students who utilized the PDCA feedback and multiple submission method scored higher than those who did not. The "delta" column in Exhibit 8 shows the difference in the average grades between the two groups for each assignment and overall. When omitting the "awareness" assignments with no significant difference, the average difference in grades is 10.5 points. This difference meets the target condition of increasing a student's score by a full letter grade using the PDCA grading format. While this study was clearly limited to one course during one semester with only 31 students, the statistically significant results are encouraging enough to pursue further research on this topic.

Based on the results of the survey, there is evidence that those students who utilized the PDCA grading option experience an increase in both the retention of learning from the course and increased confidence in the application of the course concepts. This evidence supports the two subjective hypotheses set forth by this study. Additionally, a large majority of the respondents feel the experience with the course format will benefit their engineering career. As a side note, independent of the survey, there were two students who credited the course for job offers received based largely on the knowledge, skills, and abilities gained from the PDCA format.

5. Conclusions

5.1 Recommendations

Based on the study put forth in this article, it can suggested that the PDCA pedagogy—one which emphasizes the act/adjust stage through two-way feedback along with teaching and learning toward mastery—can result in significant increases in students' performance, learning retention, and confidence in application. However, there is still much to be studied and explored on this topic.

One glaring concern over this method is the increased effort required by the instructor relative to grading multiple submissions. At times having to grade 35% more submissions became laborious compared to if the class was performed in the traditional manner. This could create a critical limitation on class sizes for which this method could be applicable. A potential way to alleviate this constraint could be to create a critical mass of PDCA mentors and graders within the department or college. Graduate teaching assistants and teacher aides would be ideal candidates to be trained in grading using the PDCA methodology. Not only would this increase capacity, it could create a synergy across all instructors and courses for the entire program.

Another potential issue with the PDCA grading methodology is the grading standard. The instructor in this course realized after the first assignment that it is important to develop criteria-based evaluation standards and grading rubrics so that students who turn assignments in early are graded to the same standard as those who do not. While subjectivity is an issue with many grading methodologies, an additional source of variation could exist in the PDCA method—grading submissions utilizing PDCA either more harshly or more leniently than the submissions that are only turned in once. The creation of criteria-based standards for grading would not only address the issue of subjectivity, but could also assist in addressing the ease of training other instructors or assistants to increase PDCA grading capacity.

An area of uncertainty exists in the applicability of the PDCA pedagogy beyond the fields of science and engineering. Would a method rooted in the scientific method be as effective or effective at all, in non-scientific fields of study such as art, history, or foreign language? One might suggest that the science in this method is not in the topic being taught, but in the act of teaching itself. This area was outside the scope of this study, but certainly lends itself to curiosity.

5.2 Areas for further study

While this article presents evidence that the PDCA pedagogy can be more effective than traditional methods, the study only covered one course, during one semester, with just 31 students being affected. This method will definitely be refined and used again by the instructor for this course in the future. However, further investigation is desired on the effectiveness of the method in other courses within the field of study, by other instructors, and in other fields of study.

The real retention of learning by the students from this semester will not be able to be measured for some time. As these students complete their studies and pursue their professional careers, it would be interesting to learn how much effect this teaching and learning style truly has. Follow up and analysis on these students and others who experience the PDCA pedagogy in the future would go a long way in understanding if putting the "act" of the plan-do-check-act cycle into action could revolutionize how college students learn.

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