# Training Students for Critical Thinking in an Electrical Engineering Core Course

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## Abstract

*Analysis and Design of Control Systems* is a core course in most Electrical Engineering programs in the United States. This course is the first course that provides a systemic view of engineering designs and links classroom knowledge to real-world applications. Training students for critical thinking (CT) skills in this class is essential to their career success. However, a high D and F grades and withdraw (DFW) rate has been observed in this course for years. The goal of this study is to redesign the course components to integrate critical thinking training into classroom activities and reform students' habits in problem-solving. The new course components include a series of lectures on cognition, critical thinking, examples of famous engineering projects with critical thinking, and decomposition of critical thinking skills in classroom examples. Evaluation of the new course module was conducted based on critical thinking assessment test, two student surveys through the semester, three classroom observations, and students' performance comparing against an untrained control group in the previous semester. Our results illustrated an effective way to improve critical thinking with this training module.

## 1. Introduction

Critical thinking is defined as "the intellectually disciplined process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, and/or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or communication, as a guide to belief and action.[1, 2] Different practice guidelines and resources have been established and available for instructors to follow for course design and instruction.[3] However, recent reports have illustrated the failure of improving critical thinking in higher education.[4, 5] Such failure is partially due to the missing training modules specifically for critical thinking skills in our higher education systems. In addition, most educators in higher education assume critical thinking training has been performed in K-12 education. Therefore, the focus on classroom instruction in higher education is transferring knowledge instead of training on critical thinking and problem-solving skills.

In this study, we proposed an easily applicable module for critical thinking training with a series of lectures on cognition, critical thinking skills, and examples of applying critical thinking skills in classroom problem solving and real-world engineering applications. Students were encouraged to foster a critical thinking habit not only in this course but also in other courses and daily life.

Evaluations of critical think capability were carried out based on student surveys and performance of 20 students (training group) who had the critical training against a group of 33 students (control group) who did not have such training.

## 2. Design and Development of the Course Module

The course module includes activities that foster students' habit of critical thinking and introduce students to research, experimentation and engineering design to reinforce the critical think skills during the semester. Blueprint of the training design was illustrated in Figure 1.

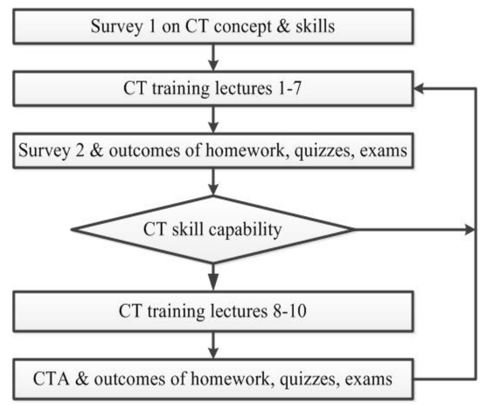


Figure 1. Blueprint of course redesign with critical thinking training module.

### 2.1 Student Survey and Critical Thinking Assessment

Two student surveys were conducted through the semester. Survey 1 focusing on fundamental concepts of engineering design and critical thinking skills was conducted within 1 week of the semester. Evaluation results of Survey 1 were integrated into the lecture series 1-7 to better adapt special needs illustrated by survey 1. Impacts of CT training lectures 1-7 was further examined by outcomes of students' performance on homework, quizzes, and exam 1 and survey 2. Survey 2 focusing on the practice of critical training skills was conducted at week-8 of the semester. Evaluation of CT skills and impact of CT on student performance was conducted to redesign CT training lectures 8-10. A critical thinking assessment (CTA) was conducted to examine students' critical thinking skills at the end of the semester. All data collected in this semester would be stored and further analyzed to improve CT training in this course in the following semesters.

Interestingly, results from the 1st survey illustrate that majority of our 3rd-year college students even do not know what is critical thinking, nor that they can be trained to improve their critical thinking skills, suggesting an urgent need to introduce specific CT training in K-12 education early.

### 2.2 Lectures series

To train students with basic knowledge on critical thinking and foster their habits of critical thinking, a series of 5 minutes lectures were integrated into lecture time each week. The topics of the critical thinking training module were listed in Table 1.

| Table 1: Lectures on Critical Thinking |
|---|
| Lecture 1: What is engineering and history of control engineering? |
| Lecture 2: Working mechanisms of human brain and memory |
| Lecture 3: What is thinking? What is Critical thinking? |
| Lecture 4: Metacognition: Thinking about thinking |
| Lecture 5: Experimental results to knowledge discovery |
| Lecture 6: Define problems with known information and aims |
| Lecture 7: Engineering reasoning and problem-solving |
| Lecture 8: Failure of critical thinking: Loss of the *Space Shuttle* Columbia |
| Lecture 9: Success of critical thinking: Greatest engineers in history |
| Lecture 10: Applying CT skills in daily life |

### 2.3 Guidelines to Foster Critical Thinking Habits

To foster students' habit of critical thinking, a list of questions was given to students for them to fill out for each problem they faced in the class for the first 4 weeks.

Q1 *What was the **purpose** of the problem/experiment/report?*
Q2 *What **point of view** did the problem/experiment/report represent?*
Q3 *What are the **assumptions**?*
Q4 *What **information** did the problem/experiment/report provide?*
Q5 *What are the **concepts** upon which the information rests?*
Q6 *What is the **conclusion**?*
Q7 *What are the **implications**?*

An example of applying critical thinking skills to a classroom problem was given as follows.

***Example Problem***: Considering a unit negative feedback system with a forward transfer function as $G(s)=\frac{s+k}{s(s+3)}$, is it possible to choose a parameter k such that the desired percentage over-shoot ($M_p$%) is less than 5% and the peak time ($T_p$) is less than 1 second?

We analyzed this problem following the question list provided above.

Answering questions 1-7 was required in the class.

Q1: T*he **purpose** of the problem is to choose system parameter K based on time domain performances* $M_p$% and $T_p$.

Q2: *The **point of view** is an engineering design problem.*

Q3: *The **assumptions** are peek-time <1 second and percentage over-shoot < 5%;*

Q4: ***Information** related to this problem includes the following knowledge points:*

1) Time domain performance knowledge in the ongoing lecture:

$$T_p=\frac{\pi}{\omega_n\sqrt{1-\xi^2}}<1$$

$$Mp\%=e^{-\pi\xi/\sqrt{1-\xi^2}}\times 100\%$$

2) System parameter for a closed-loop transfer function from previous lectures:

$$T(s)=\frac{G(s)}{1+G(s)}=\frac{s+k}{s^2+4s+k}$$

$$4=2\xi\omega_n,\qquad k=\omega_n^2$$

Q5: ***Concept** related to this problem includes getting close-loop transfer function and mapping system parameter to performance.*

*From Mp%<5%, we get* $\xi<0.707$*;*
*From Tp<1second,* $\omega_n>4.44$*;*

*From* $4=2\xi\omega_n$, $\xi=1/\omega_n<0.707$, *thus,* $\omega_n>2.82$

$$k=\omega_n^2>4.44^2$$

Q6: ***Conclusion*** *for the problem: yes, there exist such k to satisfy both performance indexes.*
Q7*:* ***Implications*** *of the problem include a backward engineering design procedure: choose RLC components for electrical systems or mass-spring coefficients for a mechanical system for a proper parameter k based on time domain performances.*

Repeating this procedure in the classroom-teaching fostered students' habit of critical thinking and confirmed them that critical thinking was really a habit and could be obtained by training and practices. With these 4 weeks of training, computer projects were assigned to reinforce students' critical thinking skills with group discussions.

# 3. Evaluation

### 3.1 Student Enrollment

A total of 53 students were enrolled in this study, of which 20 students registered in the course with critical thinking training module and 33 students were in the untrained control group. A summary of student characters was shown in Table 2. No significant difference in students' demographics and performance was observed between the training and control groups.

Table 2. Characters of students in this study

| | Training group | Control group |
|---|---|---|
| Number of Students | 20 | 33 |
| Number of Males | 17 | 26 |
| Number of Females | 3 | 4 |
| Average ± SD of overall GPA | 3.09±0.35 | 3.05±0.48 |

### 3.2 Outcome Measures

Outcomes measured in the study include students' critical thinking skills, academic performance, and 3 classroom observations conducted at week 8-10 in the semester, and persistence in the study. These outcomes were measured using the following criteria:
1) Critical thinking skills: Critical thinking skills were assessed using the Critical Thinking Assessment Test, Surveys 1 and 2, and classroom activities.
2) Academic success was assessed using grades in this class.
3) Interest in engineering: changes in interest in engineering were measured using surveys at the beginning and middle of the semester.
4) Persistence in the study: attendance rate during the semester and DFW rate of the course.

### 3.3 Statistical Analysis

Paired t-test was performed to assess changes in interest in engineering in the study. Statistical significance was established with a p-value less or equal to 0.05. Academic performance was evaluated based on the average grades in two student groups.

# 4. Results

### 4.1 Critical Thinking Assessment

Training group demonstrated a significant improvement in critical thinking skills with the CTA at the end of the semester as shown in Table 3. A total of 36 sets of effective CTA were collected (16 from training group and 20 from the control group). About of 40% of students in the control group obtained a score below 60 out of 100 while only 12.5% of students got a score below 60 in the training group. 56% of students in training group obtained a score greater or equal to 70/100 through the CT training while the only 30% of students from the control group (Table 3 and 4). In addition, no student in control group got a score above 90 while 6.25% got this high score in the training group. All these results illustrated a significant improvement in critical thinking skills in the training group.

Table 3: Distribution of CTA results from control and training groups

| Score out of 100 | Control group | Training Group |
|---|---|---|
| < 60 | 40% | 12.5% |
| 60-69 | 30% | 31.25% |
| 70-79 | 25% | 31.25% |
| 80-89 | 5% | 18.75% |
| 90-100 | 0 | 6.25% |

Table 4. Students' performance in the course and critical thinking skills

| | Training Group | Control Group |
|---|---|---|
| Average ± SD Course Grading | 2.75±0.98 | 2.39±0.85 |
| Average ± SD of CTA | 69.6±9.6 | 59.5±9.93 |
| CTA score >70 | 56% | 30% |
| DFW Rate | 10% | 15% |
| Average attendance rate | 85% | 76% |

**4.2 Impact of Critical Thinking Training on Student Performance**

While an average of CTA score of training groups was 69.6 against the average of 59.5 for students from the control group, the average grade of the course was 2.75/4 in the training group compared to an average of 2.39/4 from the control group, about 9% improvement (Table 4). This elevated average score was accompanied by a reduced DFW rate, 15% in control group and 10% in training group.

**4.3 Persistence in Study**

No student in training group dropped the course while 1 student dropped in the control group. Also, the attendance rates collected during the 16 weeks was calculated for average. A higher attendance rate 85% in the training group was observed compared to 76% in the control group.

A better student-instructor interaction and student-student interaction was demonstrated from the three classroom observations. Percentages of student's activity (red) and instructor's activity (blue) were shown in Figure 2 in one classroom observation.

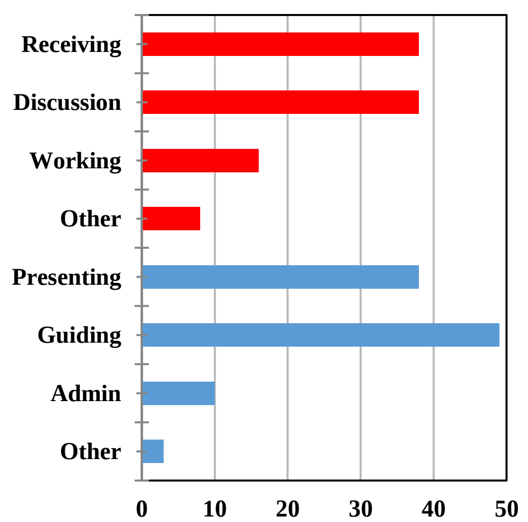


Figure 2. Students' (red) and instructor's (blue) activities (percentage of class time) were shown.

In Figure 2, the instructing guiding on student work accounted for 49% of class time and a reduced instructor presenting time (38%) was recorded. In addition, students receiving, group discussion, and hands-on working time were 38%, 38%, and 16%, respectively. With the guided student working, it was much easier for students to understand the knowledge points and apply the newly acquired knowledge to problem-solving.

## 5. Conclusion

With this project, a total of 10 course modules were developed to training students' critical thinking skills in an Electrical and Engineering core course: *Analysis and Design of Control Systems.* Course outcomes illustrated an improvement of classroom performance and CTA based on average grades for training group against the untrained control group, suggesting an effective way to improve critical thinking skills with this module. In addition, an enhanced interest in the course was suggested by frequent visits to the instructor's office and reduced DFW rate.

## Acknowledgment

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