

A Teaching Module for the Nyquist Stability Test Using Cooperative Learning

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Abstract

We describe a three-class instructional module using cooperative learning to teach the Nyquist stability criterion in an undergraduate controls class. This effort brings modern educational methods, specifically cooperative learning, into a mainstream engineering course. The Nyquist criterion was selected since it is typically the most difficult topic for students in control systems. The module consists of PowerPoint slides for the lectures, an instructor's guide, in-class group exercises, and home assignments. The module was assessed by instructor observations, a post-module quiz, student questionnaires and comparison of student exam performance with previous classes.

1. Introduction

Modern teaching techniques, such as cooperative learning, hold great promise for increasing the effectiveness of engineering education by improving student's comprehension, thinking skills, motivation, retention of information. Cooperative learning is seen by many as a means to increase student retention. Cooperative learning, when used with both group rewards and individual accountability has been shown to increase student learning¹. Cooperative learning in Engineering has been seen to improve student attitudes toward learning, student motivation, and the classroom environment^{2,3}. Much work has been done to integrate cooperative learning into the first two years in the NSF sponsored Foundation Coalition (FC) and similar programs. The work described here is part of a multicampus, multidisciplinary effort of the FC to integrate cooperative learning into mainstream junior and senior level engineering courses.

Our goal was to integrate cooperative learning into the typical senior level Control Systems course, covering classical control analysis and design using frequency domain and root locus methods. One of the most difficult topics in this class is the Nyquist stability criterion, so this topic was chosen for a three 50-minute class teaching module utilizing cooperative learning.

2. Description of the Course

The cooperative learning module for the Nyquist criterion was used in the course ECE 475, Control Systems Analysis, which is a classical control course taken primarily by seniors in Electrical and Computer Engineering. In addition to the Nyquist Stability module, cooperative learning and teaming were used extensively in the class through group homework assignments, four 10-minute group presentations, and in-class group exercises. Individual accountability was maintained by midterms, a final exam, and weekly quizzes. To promote positive interdependence, teams whose members scored well on quizzes (9 or 10 out of 10), or who beat their average score by 1 or 2 points earned bonus points for their team. This permitted all students to contribute to the success of their team, even with a diversity of ability and preparation¹. Students were organized into teams of 3 or 4 at the beginning of the semester. The groups were selected by the instructor to insure diversity of ethnicity and GPA within the groups, and balance of GPA's across the groups. Two graduate students also were in the class, and placed in a single team of 2. The assessment data reported here is for the undergraduates only. The in-class groups were self-selected, but generally were the same as the home assignment groups.

3. Description of the Module

The module consists of an instructor's guide and PowerPoint slides for three 50-minute classes. The slides include both lecture material and in-class cooperative learning exercises. The instructor's guide includes learning objectives, justification for the module, prerequisites by topic, a description of the classes, home assignments from Dorf and Bishop⁶, and a list of references on cooperative learning.

The objectives of the module are:

At the end of this module, the students should be able to:

1. Discuss encirclement, enclosure, and the Principle of the Argument.
2. Draw the Nyquist contour, explain why it looks the way it does, and draw the Nyquist diagram by referring to the Bode diagram.
3. Determine the stability of a system from the Nyquist diagram.
4. Compute phase and gain margins from the Bode diagram.

The module consisted of three 50-minute classes, with the following content:

Class 1. Contour Mapping, Principle of the Argument, Nyquist Stability Criterion

Goal: At the end of this lecture each student should be able to discuss encirclement, enclosure, and the Principle of the Argument, map contours using simple mapping, draw the Nyquist contour, and explain why it looks the way it does.

- I. History of the Nyquist Stability Criterion
- II. Contour Mapping
- III. Principle of the Argument

IV. Nyquist Stability Criterion

Class 2. Drawing the Nyquist Diagram.

Goal: At the end of this class each student should be able to draw the Nyquist diagram using the Bode diagram of the loop transfer function as an aid, and determine stability of the closed loop system.

- I. Nyquist Stability Test
- II. Polar Plots
- III. Drawing the Nyquist Diagram

Class 3. Phase and Gain Margins.

Goal: At the end of this class, each student should be able to determine the phase and gain margins of a feedback system from the Bode diagram of the loop transfer function.

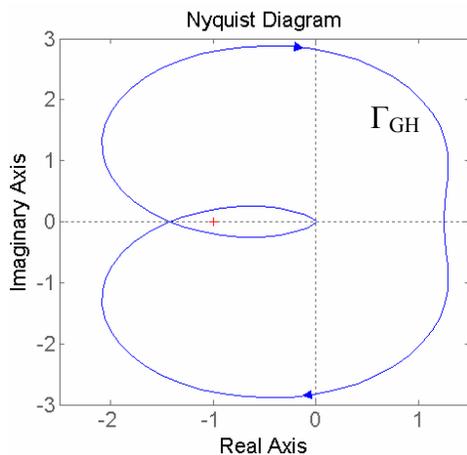
- I. Nyquist Stability Test
- II. Example of a Third Order System
- III. Stability Margins
 - a. Gain Margin
 - b. Phase Margin
 - c. Design Considerations

Each of the three classes included four cooperative learning exercises of about 5 minutes each. Most exercises require students to make choices among two or more options and articulate explanations of those choices.

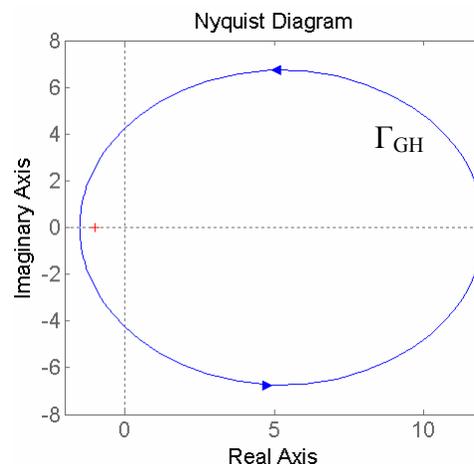
Examples:

Exercise: Which $GH(s)$ yield stable closed loop systems? Give an explanation.

$$GH(s) = (s+2)/(s^2+.5s +2)$$

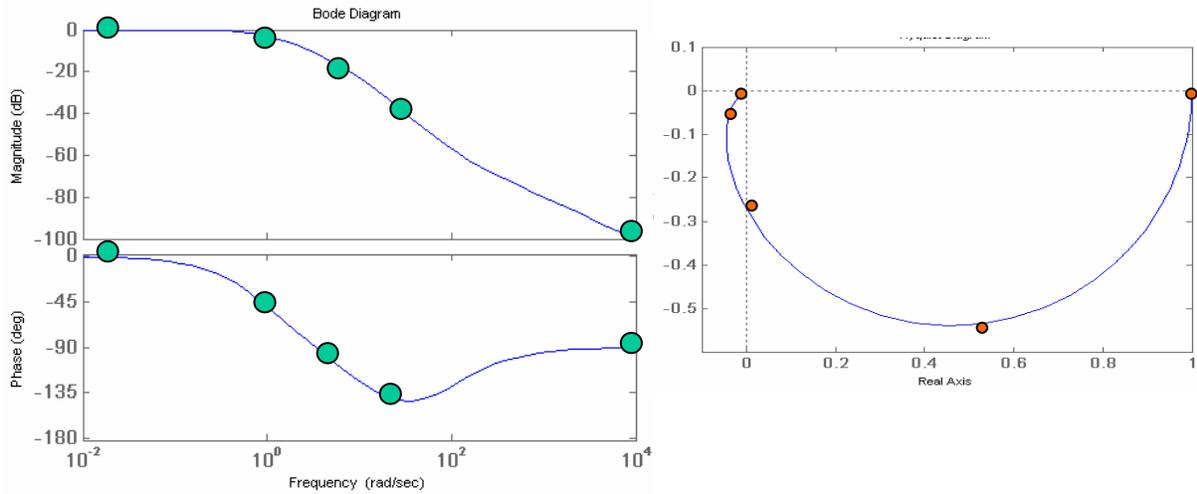


$$GH(s) = (6s+12)/(-4s+1)$$

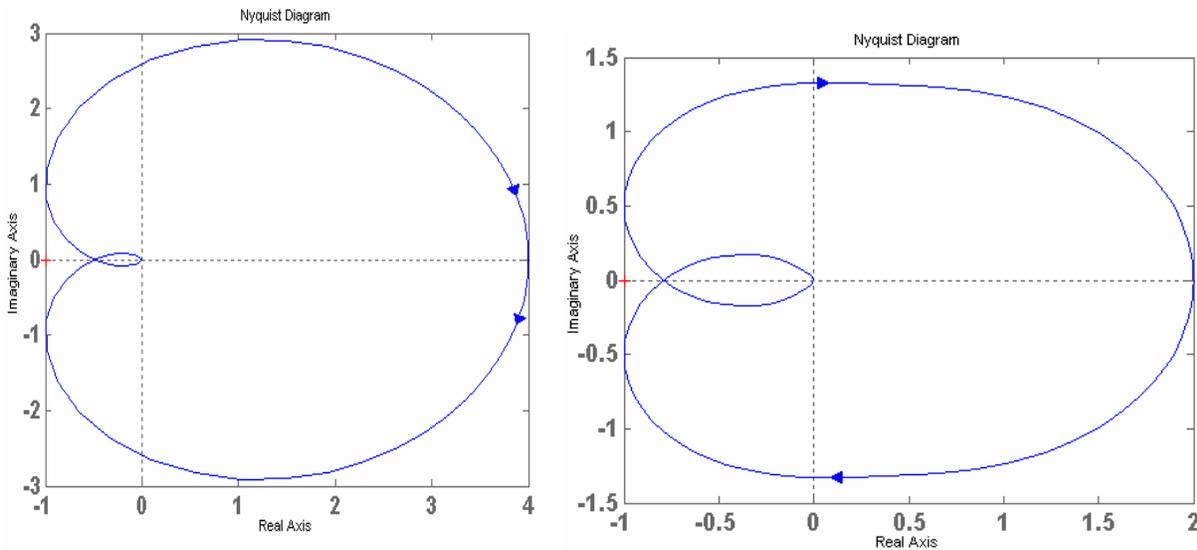


Exercise: Let each person in the group take one of the five points on the Bode Plots.

Find the corresponding point on the polar plot.
 Explain to your group why it was there.



Exercise: Which of the following Nyquist Diagrams has the largest Gain margin? Explain.



These choice-plus-explanation exercises were both time efficient, and forced the students to reflect on concepts in a way that solving exercise problems individually does not. Articulated explanations are a strength of cooperative learning, and are not addressed by most problem set assignments. After most exercises, one student from each group was either called on or self selected to report and explain their team's results to the class.

4. Classroom Testing and Assessment

The module was tested in a class with 14 undergraduate students during the Fall semester, 2002. The three 50-minute classes were taught, and followed by a homework assignment on the Nyquist criterion. This is a somewhat small sample size, and we will continue to use the module in the future to obtain a larger collection of assessment data.

Informally, from observation shortly after the module, the students appear to comprehend the material better than in previous years. As an unanticipated benefit, preparing cooperative learning exercises forced the instructor to pay more attention to the thinking skills needed to understand and apply the Nyquist criterion, and to address these skills in class. These skills included:

- Visual mapping of contours.
- Drawing polar plots ($\text{Im}[G(j\omega)]$ versus $\text{Re}[G(j\omega)]$) from Bode plots.

More formally, student learning was assessed by questionnaire and by comparison of student performance on a Nyquist criterion problem on the final exam with that of the previous year's class, which was not taught using cooperative learning.

The students completed the questionnaire after working and turning in the homework assignment associated with the module. A pre-module questionnaire was not used. It listed the eight course topics that had been covered by that time, which were:

1. Laplace Transforms; 2. Bode Plots; 3. Modeling Mechanical Systems; 4 Obtaining a Block Diagram for a System; 5. Transient Response; 6. Steady State Error; 7. Routh-Hurwitz Stability Test; 8. Nyquist Stability Test.

In question 1, the students rated the difficulty of the topics on a five-valued scale of 1. "Very Easy" to 5. "Very Hard." The average rating is shown in Figure 1.

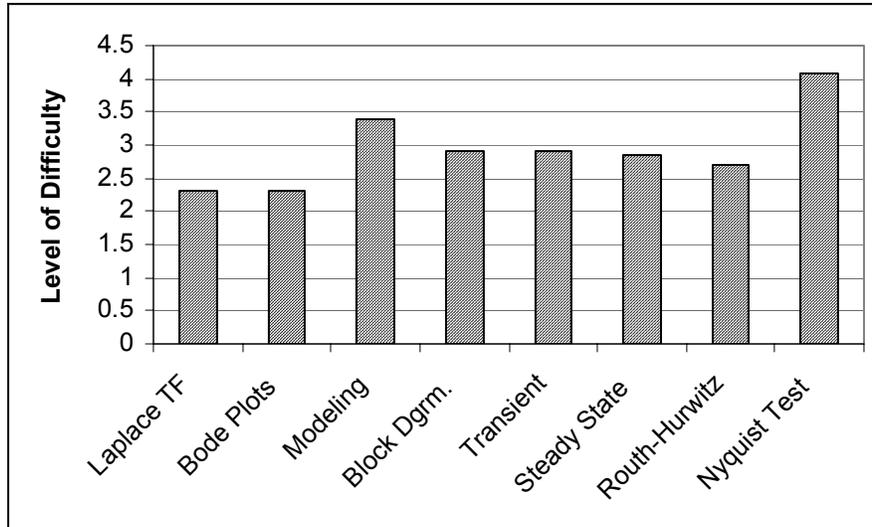


Figure 1. Student perception of the difficulty of course topics.

As can be seen, the students still perceive the Nyquist criterion as the most difficult topic in the course up to that point.

In question 2, the students were asked if they agreed with the statement ‘I am confident in my ability to use the following to solve engineering problems.’ on a scale of 1. “Strongly Disagree” to 5. “Strongly agree.” The average confidence levels are reported in Figure 2. As can be seen, the students still consider the Nyquist criterion their most challenging problem.

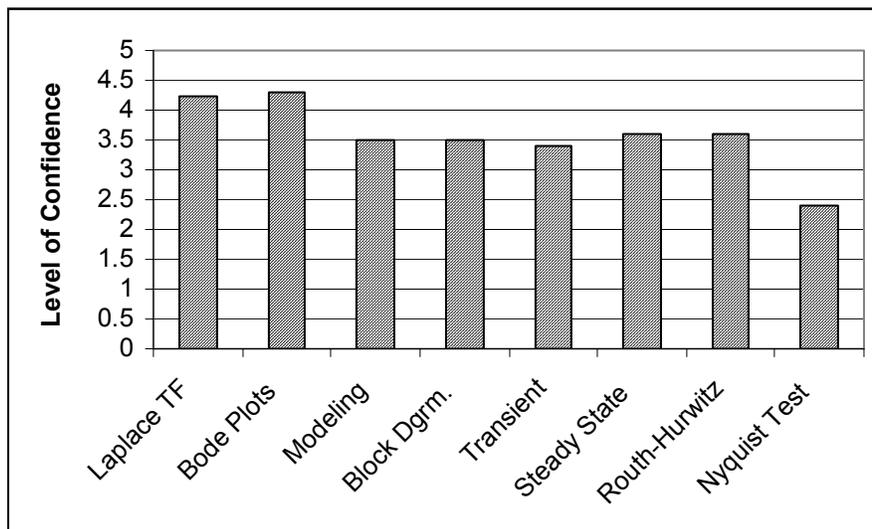


Figure 2. Student confidence level in the course topics.

Question 3 asked students to rank order the eight topics by order of difficulty, with 1 being the most difficult. The average ranks are shown in Figure 3. As can be seen, topic 8, the Nyquist criterion, was still perceived as the most difficult.

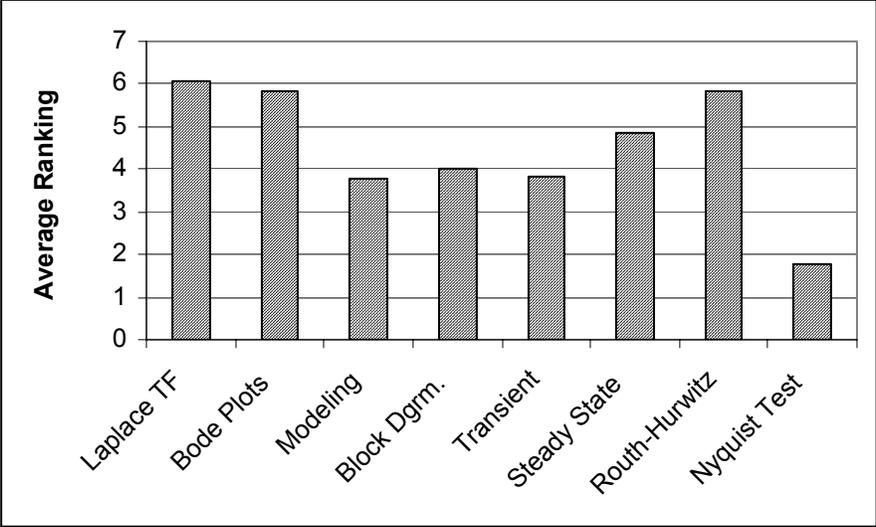


Figure 3. Difficulty ranking of the eight course topics.

Question 4 asked the student to evaluate components of the module on their helpfulness. The components were 1. Lecture, 2. In class exercises, 3. Descriptions in textbook, 4. Homework assignments, 5. Copies of PowerPoint slides. The components were evaluated on a scale of 1. Waste of Time, 2. Not At All Helpful, 3. A Little Helpful, 4. Helpful, 5. Very Helpful. The average ratings are shown in Figure 4.

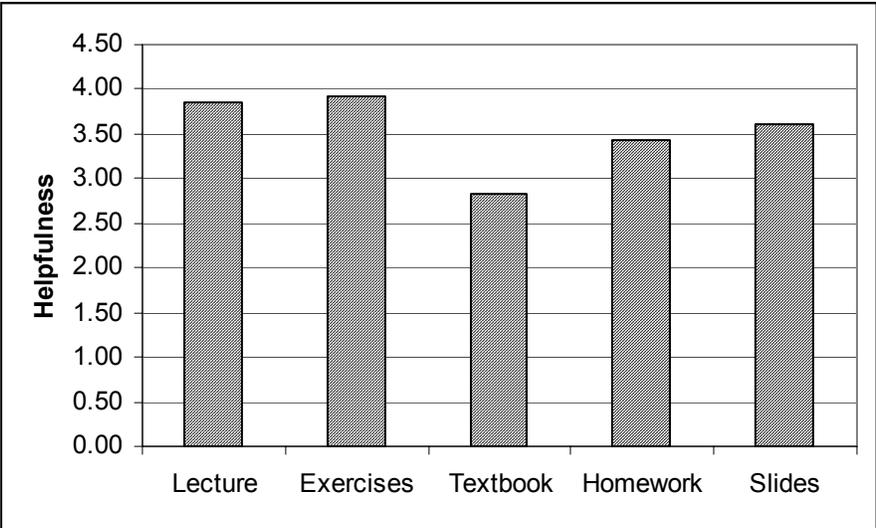


Figure 4. Average helpfulness rating of course components.

Note that the in-class exercises, item 2, which used cooperative learning, was chosen as the most helpful, and the textbook description was chosen as the least helpful. The lectures and copies of the PowerPoint slides were also highly ranked.

Students were also asked to comment on what they liked best and least about the section on the Nyquist criterion. In general, the students liked the availability of PowerPoint slides, and liked the connection with Bode plots, a more familiar subject. Many indicated they were still confused about the Nyquist criterion.

Immediately after completing the home assignment, students were given a quiz and asked to draw the Nyquist diagram and determine the phase and gain margins given the Bode diagram for a third order system. 50% (7/14) students worked both problems correctly, and 6/14 students received scores of 5/10 or less. Since the quizzes were not given in previous years, there was no way to compare these results to those obtained without the module.

A final assessment was to compare student performance on a final exam question on the Nyquist criterion to a similar question on the previous years final exam. In both years students were told beforehand that a Nyquist criterion question would be on the exam. Two of the students had not earned a passing grade the previous year, and so are included both times. For the purpose of this study, the answers were classified according to the number of conceptual errors (which was different from the actual exam grading). The results are given in Table 1.

Number of Conceptual Errors	Year 2002 Number of Students	Year 2001 Number of Students
0	2	4
1	2	2
2	6	2
3	1	0
Way Off	3	4

Table 1. Comparison of student performance on final examination question.

Here only two students from the cooperative class worked the problem correctly, while four students from the previous year did so. It should be pointed out that this is a small sample size, with 14 students in 2002, and 12 students in 2001, and that the classes were not matched for GPA's. The student GPA distribution for both years is given in Figure 5 below. As can be seen, there are no students with GPA's over 3.5 in the 2002 (cooperative) class. The average GPA (before the class) was 2.91 in 2001 and 2.79 in 2002.

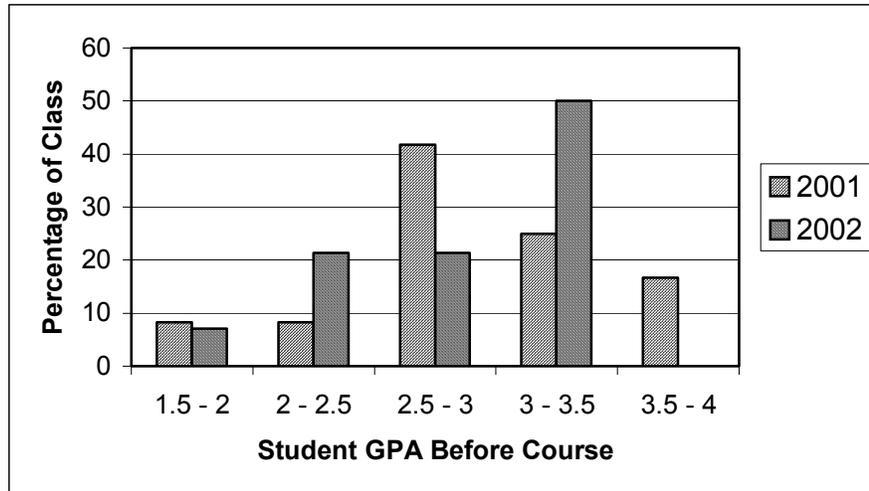


Figure 5. Student GPA's for 2001 and 2002.

The lower GPA's may also be a factor in student performance. The sample size is also fairly small, and further testing is required to properly assess the impact on student learning. The final exam questions were also not identical, and this may account for some of the difference. The students taking the 2002 final examination indicated more frequently that they did not have enough time to finish the exam, than those in 2001. The fact that half (7/14) of the cooperative class were able to solve a quiz problem immediately after the module, but only 2 of those students correctly worked the problem on the final examination may indicate the material was not processed sufficiently by the students to achieve long-term memory.

5. Conclusions and Further Research

We prepared a three-class teaching module on the Nyquist Stability criterion that used cooperative learning, and tested it in a class of 14 undergraduate students. Student performance was very good on a quiz administered directly after the module, and student understanding appeared to be excellent at that time. However no gains, and perhaps a slight loss, was seen in student performance on the final exam about six weeks later when compared to the previous year, which was taught in the traditional (lecture) manner. The small sample size for each class, and the higher GPA's in the traditional class may also be a factor. Students indicated on questionnaires that the cooperative learning exercises were the most helpful course component for learning the Nyquist criterion, but still considered the Nyquist criterion the most difficult topic in the course.

Student retention of information appears to have been a key issue in the final exam assessment. Research suggests that long-term memory is improved if the material is processed by the learner at a deeper level, which occurs when it is more meaningful to the student². The module will be revised with this in mind.

Acknowledgement

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Biographical Information

Robert Leland was born in New York City in 1956. He received the S.B. degree in Computer Science from MIT in 1978, the M.S. degree in System Science from UCLA in 1982 and the Ph.D. degree in Electrical Engineering from UCLA in 1988. He served as a visiting assistant professor in Electrical Engineering at the University of Minnesota from 1989-1990. Since 1990 he has served on the faculty at the University of Alabama in Electrical and Computer Engineering. His research interests include control systems, MEMS, engineering education, stochastic processes, atmospheric optics and fuzzy systems.