Effectiveness of Peer Instruction in a linear algebra class within an engineering curriculum

Abstract— **The effect of the Peer Instruction (PI) method in a linear algebra course within an engineering curriculum is evaluated, comparing student prior knowledge, exam performance, and perception of PI as compared to the traditional method. To assess its effectiveness, a diagnostic test, two exams, and a Student Evaluation of Educational Quality questionnaire were conducted in the experimental and control groups. Findings show that students have similar inter-group prior knowledge and that PI has greater impact on students' exam scores and satisfaction with the teaching approach than the traditional method. According to the study's subjects, Peer Instruction facilitates increased classroom interaction, inspires greater instructor enthusiasm, and contributes to enhanced reading materials. Furthermore, the more active classroom participation inherent in PI motivates students and promotes a positive attitude toward learning. In sum, Peer Instruction could constitute a valuable teaching approach in stimulating intra-student engagement in a more meaningful learning environment.**

Keywords— Linear algebra; peer instruction; traditional method; SEEQ.

I. Introduction

Failure rates among first-year engineering students are increasingly encountered in universities worldwide [1]. A contributing factor to these high rates is the inadequacy of the students' academic background in mathematics [2].

The traditional lecture (TL) approach is still the predominant teaching method at universities [1-2]. Its philosophy emphasizes the imparting of knowledge and focuses on the instructor's transference of content to a passive group of learners. Student performance is continually evaluated through tests and exams, and students endeavor to assimilate the content that will be covered. Traditional lectures lead students to memorize facts and other data for exams, rather than stimulate their capacity for creative, critical thinking.

Accordingly, the need to change the way students are taught is increasingly apparent [3-4]. When instructors change their approach, it affects student interaction, participation, and performance [5]. In particular, when an active learning method is adopted students change from passive recipients to active participants with primary responsible for their own learning [6-8].

The linear algebra class is one of the first courses to confront engineering students with definitions, theorems, and proofs. Research indicates that some factors contributing to students' lack of understanding of linear algebra include the lecturer and lecturing style, as well as such concepts as abstraction and significance [9]. Furthermore, student difficulties generally arise in understanding abstract concepts rather than in calculating computations [10-11].

This study evaluates the relative effects of Peer Instruction (PI) as compared with the traditional lecture approach on engineering students' performance and motivation in a linear algebra course. To gauge its effectiveness, the study contrasts results from a class taught using PI with two classes using the traditional method. To this end, students' exam performance and evaluation of teaching quality were reviewed. In addition, a diagnostic test was conducted at the onset of the study to identify any prior differences among students.

Peer Instruction is a student-centered, interactive teaching method developed by Mazur, professor of physics at Harvard University [12]. PI has been extensively used in courses [13-16] and has demonstrated of its effectiveness [17-20]. Peer discussion requires students to analyze concepts and share their understanding. Accordingly, PI uses exercises featuring conceptual questions in and out of the classroom to focus students' attention on fundamental concepts.

The present study implemented PI throughout the linear algebra course in the chemical engineering program at Brazil's Federal Univerisity. The Didactical Engineering methodology (DE), developed by Artigue, was instrumental in this process [21]. As a research methodology, DE is an experimental design based on a sequence in design, organization, implementation, and analysis of classroom teaching [Anonymous 2009][23-24]. Accordingly, DE can contribute to developing a didactical sequence capable of attaining desired learning outcomes.

The Student Evaluation of Educational Quality (SEEQ) questionnaire, one of the most widely used evaluative instruments in higher education, was administrated to students in the three study groups in the final third of the course. SEEQ, which is based on psychometric analysis, was developed by Marsh [25] and has been extensively researched [26-31]. Its formal student rating provides useful data to diagnose teaching effectiveness, thus providing feedback to instructors, and to judge the impact of instructional strategies on diverse students in different courses and settings [32].

While PI has been broadly implemented and widely researched, it is not known to be a common practice in linear algebra courses in Brazil. Most Brazilian instructors have neither the time nor the incentives to change their teaching practices.

Accordingly, the present study combines a well-regarded active learning method, i.e. Peer Instruction, with a well-designed research method, i.e., Didactical Engineering, and a well-established evaluation instrument, i.e., SEEQ, to enhance teaching strategy. This is the principal innovation presented in this study.

The remainder of the paper is structured as follows: The second section describes the implementation of PI and TL methods in the classroom and the instruments used to evaluate their effectiveness. The third provides data from the diagnostic test, exams, and the questionnaire; while the next discusses their implications for teaching effectiveness. The final section summarizes the study's principal findings and notes next steps.

II. METHOD

The study was conducted in the second semester of 2014 at Brazil's Federal University. It compares a linear algebra class using PI (hereafter, PI class) with two others using the traditional lecture method (hereafter, TL1 and TL2). Part of the engineering curriculum, the PI class was conducted in the Department of Chemical Engineering, while the others occurred in the Department of Energy and Environmental Engineering.

Linear algebra is customarily taught first-year engineering students as 64-hour course, consisting of 2-hour classes held semiweekly. The three classes covered the same material in the same sequence, i.e., matrices, determinants, linear equations, vectors, line and plane equations, vector spaces, basis, linear transformation, orthogonality, eigenvalue and eigenvector, and diagonalization. The initial diagnostic test, two exams, and the SEEQ questionnaire were administered at approximately the same junctures.

A. Peer Instruction class

The Peer Instruction class was composed of 75 students, of whom 26 were female and 49 male. In addition to its PI methodology, the class incorporated Didactical Engineering, as an organizational, observational, and feedback mechanism and Just-in-Time Teaching (JiTT) as a key component in its reading assignments [33].

The PI instructor conducted in-class, multiple-choice polling to assess students' mastery of linear algebra concepts and thereby enable ongoing instruction to increase their understanding of such fundamental abstractions and promote interactive classroom participation.

In addition, targeted, pre-class reading assignments were critical to the PI method since they prepare students to grasp concepts more readily and to participate in classroom discussion more knowledgeably. As an incentive to complete these assignments, a modest factor, i.e., 10%, was added to the exam grades of students who did so.

In accordance with JiTT, students were expected to submit their reading assignments prior to the subsequent class to enable the instructor to address student difficulties thus identified in its content. However, due to time constraints, in the present study, students returned their assignments at the beginning of the next class, and the instructor had already prepared its content based on anticipation of student difficulties derived from teaching experience [21]. Subsequent to the class and her assessment of the complete assignments, the instructor reviewed her previous assumptions and revised the content of the next class, as needed, to address any concepts requiring clarifications. For a graphic representation of the instructional sequence in the PI class, see Fig. 1 (For addition details about its components, see [Anonymous, 2016]).

Whenever opportune, definitions, abstract concepts, and theorems were introduced throughout exemplificative, simpler versions of themselves. Only upon student's solid understanding of special cases that more elaborate, and general versions were discussed. Such initiative aims at overcoming pedagogical barriers to linking concrete and abstract concepts, and thus helping students to surpass primary theoretical difficulties. Accordantly, the flux activity in class trended from the concrete to the abstract, evolving, whenever possible, from geometric visualizations and physical interpretations to more abstract ideas of the course.

B. Traditional lecture class

The subjects enrolled in the morning traditional lecture class constituted 63 students, 36 male and 27 female, while those enrolled its evening counterpart consisted of 47 students, 29 male and 18 female.

The TL instructor customarily provided students unit lecture notes in advance so that they could read them before class. Class time was largely spent on lectures demonstrating theorems and solving textbook problems with occasional, limited student participation. For each unit, the instructor provided homework, and students were free to request the aid of a teaching assistant. Moreover, the instructor conducted a review session prior to each examination.

C. Evaluative instruments

Students' diagnostic tests, exam performance, and the SEEQ questionnaire were reviewed to compare PI's effectiveness with that of the traditional lecture method.

To determine subjects' prior knowledge of linear algebra, a diagnostic test was administered at the onset of each of the three classes. The test consisted of ten true-or-false questions covering such fundamental concepts of linear algebra as matrices, systems of linear equations, determinants, notions of vectors, and line and plane equations [Anonymous, 2015]. In addition to true or false, possible responses included unknown content, never studied, or have studied but cannot solve, with the additional responses aggregated as blank responses. As the test was conducted solely for diagnostic purposes, its results were not included in students' grades.

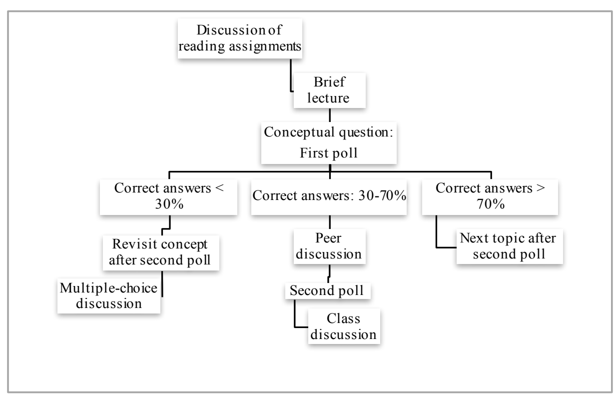

Fig. 1 PI class instructional sequence.

Exams, comprising open-ended and true-or-false questions that assess expected learning outcomes, were administered at the end of the first and second third of the course. They covered the content of the preceding period and included conceptual and problem-solving questions. The first also included the notion of vector space and subspace, while the second included vector space, span, basis, and linear transformation. A statistic t-test was used to compare the classes' mean scores.

The original SEEQ questionnaire comprises 40 questions measuring nine factors of teaching effectiveness: learning/value, enthusiasm, organization, group interaction, individual rapport, breadth, examinations/grading, assignments/readings, and workload/difficulty. This study used an adapted form consisting of 35 questions and ten factors, previously validated for Brazil via confirmatory factorial analysis [Anonymous, 2013]. (See, Table I.) It was administered in the concluding third of the course, with factors rated on a five-point Likert scale, ranging from 1 (very poor) to 5 (very good). SEEQ responses were validated using the coefficient Cronbach's alpha in each factor and a statistic t-test was used to compare the classes' mean scores.

III. Results

A. Diagnostic Test

To determine whether there were significant differences in prior knowledge of linear algebra among the classes, a diagnostic test was administrated on the first day of class. In the PI class, 80% of the students took the test, and in the two traditional lecture classes, the rates were 85% (TL1) and 95% (TL2). Fig. 2 provides the aggregate results and indicates no significant differences among the classes, with, at most, a 5% difference in the rate of correct, 3% in incorrect, and 3% in blank responses.

TABLE I. Analyzed SEEQ factors

Abbreviation*	Factor		Students' opinion of:
Lrn	Learning (4 items)		Challenge and learning value of course
Enth	Enthusiasm (4 items)		Instructor's dynamism in class
Org	Organization (4 items)		Instructor's organization and preparation for class
IntGrp	Group Interaction (4 items)		Students' engagement in class
IndRap	Individual Rapport (4 items)		Relationship between instructor and students
Brdh	Breadth (4 items)		Presentation of concepts' background, different viewpoints, and current developments
Exam	Examinations (3 items)		Instructor's assessment and grading methods
Asgn	Assignments (2 items)		Appreciation of readings, homework, etc.
O_C/I	Overall	Course (1 item)	Relative course difficulty compared to others.
		Instructor (1 item)	Relative instructor difficulty compared to others.
O_Char	Overall Student and Course Characteristics (4 items)		Relative course difficulty, class pace, and time required for outside class activity.

*N.B.: Factor abbreviations also used in all subsequent tables.

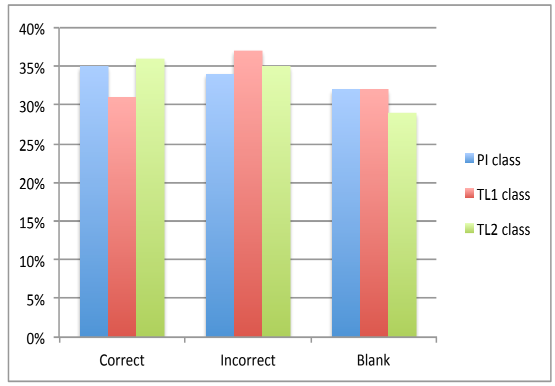

Fig. 2 Aggregate results per class.

When the incorrect and blank responses are combined, the rate markedly exceeds that correct response rate in all three classes, by 31 percentage points (PI), 38 percentage points for TL1 class, and 28 percentage points for TL2 class, indicating a relatively low level of prior knowledge (see Fig. 3.)

B. Reading Assignments

To assess the relative effectiveness of their teaching methods, student exam performance in the three classes was compared. For each exam, a t-test was used to determine whether there was a statistical difference between the PI and TL1 and between the PI and TL2 means. The results can be seen in Table II.

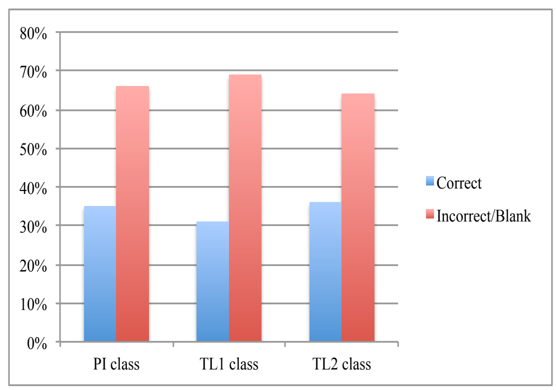

Fig. 3 Aggregate results per class, combining incorrect and blank responses.

TABLE II. Exam performance per class

	Exam 1			Exam 2		
Class	***N (% of enrolled students)***	***Mean (sd)***	***p-value***	***N (% of enrolled students)***	***Mean (sd)***	***p-value***
PI	68 (90%)	6.56 (2.28)		65(87%)	6.97 (2.55)	
TL1	59 (93%)	5.67 (2.81)	0.028	55(87%)	6.36 (3.12)	0.12
TL2	40 (85%)	5.06 (2.55)	0.001	34(72%)	5.3 (2.99)	0.0021

In the first exam, the PI class performed significantly better than the TL classes (TL1: $p < 0.028$, TL2: $p<0.001$). In the second, the PI class performed statistically better than TL2 ($p<0.0021$). Although the PI mean score was greater than the TL1, no significant difference existed between them.

When compared TL1 to TL2, there was no statistical difference between the classes in both exams (exam 1: p=0.13, exam 2: p=0.057). No further analysis will be carried out since the paper´s purpose is to compare the results obtained by the experimental class and the control classes.

Table II provides the number of students who took each exam. Comparatively, 5%, 7%, and 12% of the students did not take the second exam in the PI, TL1, and TL2 classes, respectively.

C. SEEQ questionnaire

To analyze student perception of teaching quality, the SEEQ questionnaire was administered in the final third of the course. Since the two traditional lecture classes were taught by the same instructor, both classes completed the questionnaires at the same time. The participation rate for the PI group and TL classes were 86% and 60% respectively. (For convenience, the term "students" as used in this section refers to those completing the SEEQ questionnaire.)

1. Reability

To evaluate the questionnaire's reliability, Cronbach's alpha was applied to each factor, as presented in Table III. A Cronbach's alpha value ranges from 0.0 to 1.0, with values approaching 1.00 indicating excellent internal consistency. The results found that reliability ranged from 0.60 to 0.88 on the SEEQ category subscales for the PI class and from 0.51 to 0.78 for the TL classes. Nearly all factors appeared to have greater internal consistency for the PI class with the exception of Enthusiasm and Individual Rapport. The reliability of the factors was satisfactory for the PI class, with only Overall Characteristic presenting lower internal consistency (0.60). Some TL factors also presented lower internal consistency, viz., Organization (0.54), Overall Characteristic (0.52), and Overall Course/Instructor (0.51). These values indicate a high level of error variance in the students' responses for these factors. Since the overall Cronbach's alpha for the PI and TL classes were 0.91 and 0.88, respectively, the reliability of the SEEQ questionnaire for the study's three classes was deemed satisfactory.

TABLE III. CRONBACH'S ALPHA PER FACTOR

Factors	PI Class		TC Class	
	Variance	***Cronbach's alpha***	***Variance***	***Cronbach's alpha***
Lrn	0.098	0.710	0.027	0.683
Enth	0.093	0.737	0.215	0.77
Org	0.053	0.763	0.213	0.541
IntGrp	0.001	0.876	0.018	0.771
IndRap	0.053	0.704	0.023	0.76
Brdh	0.282	0.745	0.177	0.728
Exam	0.019	0.813	0.002	0.789
Asgn	0.005	0.700	0.04	0.6
O_C/I	0.113	0.880	0.299	0.517
O_Char	0.772	0.603	0.594	0.521

2. The T-test

An independent sample *t*-test was conducted to compare SEEQ factor scores. Table IV provides the mean score, the standard deviation, and the effect for each factor per class. The results indicate there is a statistically significant difference between the PI and TL classes in their mean scores of Learning (p=0.044, d = 1.5), Enthusiasm (p=0.006, d= 2.5), Interaction Group (p=0.014, d=2.6), and Assignments (p = .038, d=3.07), and that these factors had a considerable effect, i.e., had a high practical significance in accordance to the standards reported in [36]. In the PI class, 5 of the 11 factors had mean scores exceeding 4 on a 5-point scale, viz. Enthusiasm (4.56), Interaction Group (4.43), Individual Rapport (4.40), Examination (4.21), and Organization (4.11). Such scores reflect a highly positive student perception of the quality of the PI method.

Fig. 4 depicts SEEQ results by statement for the first seven factors per class in the "strongly agree" response (See Appendix for statement´s description). It shows that PI class excelled in more than 75% of all questions when compared with TL classes. It is particularly relevant to assess the result of question 6, which inquires whether the instructor was dynamic and energetic in conducting the course. In that question, PI scored 56 percentage points above the TL classes.

For the remaining 25% of the questions, which TL classes scored better than the PI class, it is to be noted that in the strongly agree response, 57% of them laid on the Individual Rapport factor (all questions of this factor) and 28% on the Organization factor. The inference is that the TL's instructor showed to be more friendly and accessible to students.

TABLE IV. SEEQ RESULTS BY FACTOR, PER CLASS

Factors	**PI class**	**TL class**	**P-value**	**Cohen's d**	**Effect**
	Mean (sd)	**Mean (sd)**			
Lrn	3.78 (0.31)	3.4 (0.16)	0.044*	1.53	Large
Enth	4.56 (0.30)	3.57 (0.46)	0.006**	2.51	Large
Org	4.11 (0.23)	3.98 (0.46)	0.32	0.34	Small
IntGrp	4.43 (0.03)	4.17 (0.13)	0.014*	2.60	Large
IndRap	4.40 (0.23)	4.59 (0.15)	0.118	-0.94	Small
Brdh	3.56 (0.53)	3.33 (0.42)	0.265	0.471	Small to Medium
Exam	4.21 (0.14)	4.20 (0.04)	0.461	0.088	Small
Asgn	3.44 (0.07)	2.98 (0.2)	0.038*	3.07	Large
O_C/I	3.44 (0.33)	2.98 (0.54)	0.208	1.15	Large
O_Char	3.18 (0.88)	3.00 (0.77)	0.383	0.22	Small

* $p<0.05$; ** $p<0.01$

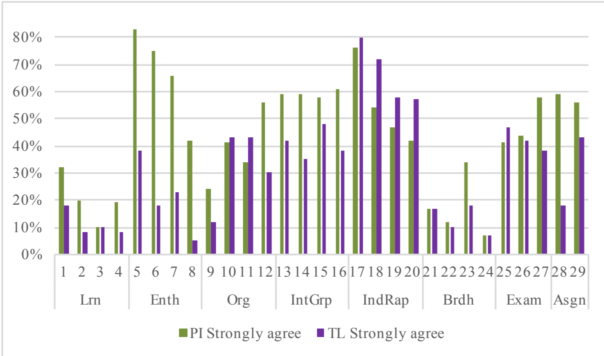

Fig. 4 Student´s opinion by factor in the "strongly agree" response, per class.

These data suggest that TL's instructor is a welcome, sympathetic, and charismatic individual. These are important personal qualities for an educator, which, nonetheless, fall into a complementary dimension of competence than the ones investigated in this study. The data also indicate that TL's instructor demonstrated to be well organized in class; a typical feature of the traditional teaching methodology. This result is in accordance with the expectation that TL classes appear to the students to be more coordinated than active methodologies.

In terms of the Overall C/I factor, the result shows analogous responses for all classes. About 39% of PI and 43% of TL students view linear algebra as a moderate course in comparison with others. In addition, 64% of PI and 47% of TL students deemed their instructor fair in comparison to others.

In regard to the Overall Characteristics factor, half the students in the PI and TL classes considered their course moderate with respect to difficulty and workload in comparison to other courses and about 45% of them found it fast-paced. Over 68% of the PI students, as opposed to 40% of TL students, spent 2 to 5 hours per week studying outside the classroom.

IV. Discussion

A. Diagnostic test

According to Fig. 3, students had similar prior knowledge of basic concepts of linear algebra. A notable finding of this study is that examination of the results of the diagnostic test administrated at the course onset reveals a significant deficiency in student knowledge of basic mathematical concepts essential to understanding linear algebra. In this regard, it should be noted that the first phase of Brazil's linear algebra syllabus comprises a review of such fundamental concepts to enable students to comprehend, enhance, and connect them to the more complex concepts to follow.

B. Exam performance

As Table II evidences, PI class students performed better in the two exams than those the traditional classes. Comparing scores in the initial exam, PI students performed better than their TL counterparts, indicating that Peer Instruction has greater impact on students' mastery of basic concepts of linear algebra than the TL method.

In regard to the second exam, PI students attained significantly higher scores than their TL2 counterparts. The overall exam findings indicate that Peer Instruction improves students' comprehension of linear algebra more effectively than the traditional lecture method.

An interesting observation is that students in all classes performed better on the second exam than on the first. This finding is consistent with the syllabus and objective of the course's initial phase, i.e., to provide a solid foundation for mastery of the next stage's concepts.

Another fact worth noting is that of the 75 students enrolled in the PI class, 21% failed the course, while 30% of the 110 enrolled of the TL classes did so. This suggests that Peer Instruction may have a positive effect on reducing student failure rates.

C. SEEQ questionnaire

As can be seen in Table IV, the PI method generated considerable positive response in the SEEQ questionnaire, which identified four factors in which it presented statistically significant differences with the TL method.

First, PI students were more likely to regard their class as stimulating. Examination of the statements that constitute the Enthusiasm factor indicates Peer Instruction creates a more dynamic learning environment for students than the traditional method.

Second, PI students appreciated their instructor's frequent encouragement to participate in class and share their ideas. This suggests that Peer Instruction may contribute to students' development of social interaction skills.

Third, PI students were more apt to find their learning process challenging and valuable. Their positive assessment could well contribute to their higher exam scores.

Finally, PI students were more likely to view their reading assignments as valuable since they increased their understanding of course material. Thus Peer Instruction's facilitation of enhanced comprehension of course content is likely to contribute to better academic performance, as evidenced by the PI students' exam grades.

These results were not unanticipated as these factors lie at heart of the Peer Instruction philosophy. Bearing in mind these significant differences, a strong case for Peer Instruction's beneficial impact on students' perception of their academic environment and thus their motivation to actively participate in their learning is quite evident.

V. Conclusion

This study reports the impact of implementing Peer Instruction in a linear algebra course on student perceptions and learning, compared with that of the traditional lecture method. The results of the study's instruments assessing students' prior knowledge, exam performance, and perceptions of teaching quality were examined across one PI and two TL classes. As documented herein, the Peer Instruction teaching method evidences significant advantages over the traditional method in number of areas, particularly in stimulating active, student participation in the learning environment, a key ingredient in academic success.

A teaching methodology that encourages engineering students to develop abstract thinking, collaborative learning, and problem-solving skills, will serve them well in their academic and professional careers. As our study demonstrates, Peer Instruction is such a method.

To confirm and enhance the value of Peer Instruction in the education of undergraduate engineering students, especially in its initial stages, we intend to amass and evaluate additional data through our PI linear algebra class. Researchers in other fields in which linear algebra plays an important role may wish to consider similar research adapted to their disciplines.

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APPENDIX

The Student´s Evaluation of Educational Quality (SEEQ) Instrument

Use the following to evaluate the first 29 statements: (Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree)

LEARNING:
1 You found the course intellectually challenging and stimulating
2 You have learned something which you consider valuable
3 Your interest in the subject has increased as a consequence of this course
4 You have learned and understood the subject materials in this course

ENTHUSIASM:
5 Instructor was enthusiastic about teaching the course
6 Instructor was dynamic and energetic in conducting the course
7 Instructor enhanced presentations with the use of humor
8 Instructor’s style of presentation held your interest during class

ORGANIZATION:
9 Instructor’s explanations were clear
10 Course materials were well prepared and carefully explained
11 Proposed objectives agreed with those actually taught so you know where the course was going
12 Instructor gave lectures that facilitate taking notes

GROUP INTERACTION:
13 Students were encouraged to participate in class discussions
14 Students were invited to share their ideas and knowledge
15 Students were encouraged to ask questions and were given meaningful answers
16 Students were encouraged to express their own ideas and/or question the instructor

INDIVIDUAL RAPPORT:
17 Instructor was friendly toward individual students
18 Instructor made students feel welcome in seeking help/advice in or outside of class
19 Instructor had a genuine interest in individual students
20 Instructor was adequately accessible to students during office hours or after class

BREADTH:
21 Instructor contrasted the implications of various theories
22 Instructor presented the background or origin of ideas/concepts developed in class
23 Instructor presented points of view other than his/her own when appropriate
24 Instructor adequately discussed current developments in the field

EXAMINATIONS:
25 Feedback on examinations/graded materials was valuable
26 Methods of evaluating student work were fair and appropriate
27 Examinations/graded materials tested course content as emphasized by instructor

ASSIGNMENTS:
28 Required readings /texts were valuable
29 Readings, homework, etc., contributed to appreciation and understanding of subject

OVERALL:
30 Compared with other courses you have taken at your department; this course was (1-Very poor ... 3-Average ... 5-Very good)
31 Compared with other instructors you have had at your department, this instructor was (1-Very poor ... 3-Average ... 5-Very good)

STUDENT AND COURSE CHARACTERISTICS: (Leave blank if no response applies)
32 Course difficulty, relative to other courses, was (1-Very easy . . . 3- Medium . . . 5-Very hard)
33 Course workload, relative to other courses, was (1-Very light . . . 3- Medium . . . 5-Very heavy)
34 Course pace was (1-Too slow . . . 3-About right . . . 5-Too fast)
35 Hours per week required outside of class 1) 0-2; 2) 2-5; 3) 5-7; 4) 7-12; 5) Over 12.