A statistical examination of student achievement and attitude in a large-enrollment, inquiry-based, introductory, biology course.

Donald P. French and Connie P. Russell

Donald P. French
Department of Zoology
430 Life Science West
Oklahoma State University
Stillwater, OK 74078-3052
405-744-9690
dfrench@okstate.edu
http://zoology.okstate.edu/zoo_lrc/biol1114/

Connie P. Russell
Department of Biology
Angelo State University
Box 10890, ASU Station
San Angelo, TX 76909
915-942-2189 ext. 251
Connie.Russell@angelo.edu
http://www.angelo.edu/faculty/crussell/

Paper presented at the
2001 Conference of the
National Association for Research in Science Teaching
St. Louis, Missouri
25 – 28 March 2001

http://zoology.okstate.edu/zoo_lrc/biol1114/guest/narst-2001.pdf

This project was funded in part from a grant by the National Science Foundation (NSF#9752402). Opinions expressed are those of the authors and not necessarily those of the foundation.

Rationale

The relationship between achievement and attitude toward science has been the focus of many science education studies. Many researchers have reported that achievement and attitude toward science are positively correlated (Russell and Hollander, 1975; Shrigley, Koballa, and Simpson, 1988), but this finding is not universal (e.g., Germann, 1988). When measures of attitude and achievement are made on specific subsets of students (e.g., males, females, majors, non-majors) the relationship may be slightly clearer. For example, many studies have indicated that males have a more positive attitude toward science (Simpson and Oliver, 1985), perform better in science classes (Steinkamp and Maehr, 1984; Tobin and Garnett, 1987; Rafal, 1996), choose science fields more often (Mason and Kahle, 1988; Ware and Lee, 1988; Maple and Stage, 1991; Seymour and Hewitt, 1997), and are more likely to remain in the field (Seymour and Hewitt, 1997). Other studies indicated no difference between males and females as to their attitude toward science (Barrington and Hendricks, 1988; Morrell and Lederman, 1998; Shaw and Doan, 1990). Germann (1988) and Gogolin and Swartz (1992) attributed this lack of consensus to the lack of a valid and reliable measurement of attitude and to poor research methodology. If success is to be achieved in developing scientific literacy, encouraging the selection of science as a career by a diverse population, and promoting life-long learning in the sciences, then the impact of new instructional styles employed in introductory science courses must be carefully evaluated in terms of attitude, content knowledge and process skills.

The National Science Education Standards (NRC, 1996) emphasize the importance of shifting toward student-centered pedagogy at the K-12 level. Recommended teaching strategies are based on aspects of traditional constructivist theory (individuals construct meaning through hands-on and minds-on experience that leads to adjustment of prior personal explanation for phenomena) and socio-cultural models of learning (individuals learn through interaction with others, both as peers and apprentices). The teacher's role in Standards-based, student-centered classes includes providing situations for active learning, facilitating student reflection, providing opportunities for peer-to-peer exchanges, and guiding students toward current, conventional scientific descriptions and explanations. While success with such methods has been achieved at the pre-college level (e.g. Von Secker and Lissitz, 1999), Standards-based practices have made limited inroads at the college level. Furthermore, the possible impact that a change in pedagogy may have in either the affective or cognitive domains has not been fully assessed, especially in large-enrollment introductory sciences courses, typically the antithesis of Standards-based classes.

The objective of this study was to compare changes in attitudes and achievement among students in introductory college-level biology courses taught following the traditional teacher-centered paradigm to those among students in a newly revised course that adopted a more student-centered approach. We further compared these changes with respect to students' sex, academic major, and class standing.

Research Questions:

- Does a revised teaching methodology that emphasizes inquiry and collaboration affect students' attitudes toward biology at the college level? We predicted, based on the philosophy espoused in the National Science Education Standards, that students taught using the student-centered paradigm would have a more positive attitude toward biology as measured by a standardized instrument.

- Does a revised teaching methodology that emphasizes inquiry and collaboration affect content knowledge possessed by students at the college level? We predicted that the greater emphasis on problem solving and an understanding of the process of science rather than rote memorization of a broad range of material would lead to improved problem-solving ability, but would not necessarily lead to improved scores on a recall level exam over a wide range of topics.

- Does a revised teaching methodology that emphasizes inquiry and collaboration affect the attitudes toward biology of different sub-groups of students (based on sex, class standing, and major), differentially? We predicted, based on the philosophy espoused in the National Science Education Standards, that all students would benefit equally from the revised teaching methodology.

- Does a revised teaching methodology that emphasizes inquiry and collaboration affect the content knowledge of different sub-groups of students (based on sex, class standing, and major), differentially? We predicted, based on the philosophy espoused in the National Science Education Standards, that all students would benefit equally from the revised teaching methodology.

Methods

Course Descriptions:

Subjects for this study were students enrolled in the introductory biology courses at a land grant institution in the south-central United States during Spring 1998 through Spring 2000 semesters. At the onset of this study, students could choose from three introductory biology courses; a non-majors course encompassing ecology, evolution, and genetics (1114-old); a non-majors course encompassing sub-cellular, cellular, and organismal biology (1214); and a science majors course encompassing cellular and molecular biology, ecology, evolution, and genetics (1304). All three courses were taught in a traditional expository style in lecture. The associated laboratories were taught following a "cookbook" approach that primarily validated or reinforced information that students had been exposed to in lecture. Students were only assessed individually.

Beginning in Fall 1998, the three courses were replaced with a mixed-majors course (1114-new) that introduced students to biological concepts integrated from the sub-cellular to the ecological through an investigative approach that encouraged students to make critical observations, formulate hypotheses, test hypotheses, and then critically discuss results. Multimedia scenarios and demonstrations served as focal points for discussions of problems that allowed students to construct concepts in an applied context. In the laboratories in the new course, students tested hypotheses that they generated in response to general research questions they encountered in lecture or in the background material for the investigations presented in the laboratory manual. In the new course, students worked collaboratively in both lecture and the accompanying laboratory. Forty-seven percent of the evaluation of each student was based on group assessment. Assessment of the students' performances in the laboratory was based on the quality of their research and not on achieving specific results. The assessment in lecture that was primarily formative was based on daily group activities. Students were only assessed individually on exams. While the students' performances in lecture in all the courses were evaluated by multiple choice exams, the questions on the exams in the old courses required primarily simple recall, while those in the new course primarily required students to apply concepts to novel situations.

Subjects:

We invited all students enrolled in the introductory courses to participate in this study. The majority of the students were in their first year. While there were different courses for majors and non-majors prior to Fall 1998, neither population was exclusively majors or non-majors. Only students who gave their informed consent (IRB#AS-98-006) and completed all components of the survey were included in the study. We obtained complete data from 306 students from 1114-old in Spring 1998, 98 students from 1214 in Spring 1998, 311 students from 1304 in Spring 1998, 406 students in 1114-new in Spring 1999, and 662 students from 1114-new in Spring 2000.

Survey Instrument:

At the beginning and end of each semester, we administered a survey instrument consisting of 40 questions from the NABT/NSTA High School Biology Examination (NABT/NSTA, 1990), a 14-item Biology Attitude Survey (Russell and Hollander, 1975) and 6 items of demographic information. We used the NABT/NSTA exam and attitude survey because they had been validated.

Students answered survey questions on computer-graded sheets, in approximately one hour. The student's response to each item on the fourteen-item attitude survey was scored on a Likert-type scale (1-5). A response of 5 indicated agreement with the statement item, a response of 1 indicated disagreement. To conform to the scale used by Russell and Hollander (1975), we generated overall attitude scores by setting the most positive response to 5 and the most negative response to 1 then summing the score. The scale was reversed for responses to negatively worded items. A score of 14 indicated a poor attitude toward biology, a score of 42 an ambivalent attitude toward biology, and a score of 70 a strongly favorable attitude toward biology.

To evaluate change in each student's content knowledge and attitude from the survey at the beginning of a semester (initial scores) and the survey at the end of a semester (final scores), we subtracted initial scores from final scores to generate change in content knowledge scores and change in attitude scores.

For analysis, students were characterized with respect to four factors. Sex was self-reported (male, female) on the survey. We classified students as either "Life Science" majors (Botany, Biology, Microbiology, Physiology, Zoology, Wildlife or the Health Sciences (premedical, preveterinary, prenursing)) or "Non-Life-Science" majors (all other majors) using the majors that students self-reported on the survey. Each student's Class Standing as reported by the university's Office of Institutional Research was coded as either first-year (freshman) or greater than first-year(non-freshman). We also obtained students' ACT scores from the Office of Institutional Research and used the composite score (i.e. the average of the four (English, Math, Reading and Science) section scores). The university's minimum ACT composite score for normal admission is 21 out of 36.

We analyzed the results of the attitude and content knowledge survey components by Analysis of Covariance (ANCOVA). The ANCOVA model represents an integration of the analysis of variance (ANOVA) and the analysis of variance of regression model (ANOVAR). We used ANCOVA rather than ANOVA because it would generate a smaller error term. ANCOVA also reduces the bias that may be caused by differences in the covariate variable(s) between groups and includes an adjustment of the treatment effect. A single covariate implies a system of several regression lines, one line for each treatment group. More than one covariate can be measured and included simultaneously in one ANCOVA. Multiple covariates imply regression surfaces.

In each ANCOVA model, the main factors or treatments were course, major, class standing, and sex. To adjust for possible differences among the students in initial knowledge or attitudes, we used the change in attitude scores and change in content knowledge scores as our dependent variables. To further adjust for differences among students' academic abilities or incoming attitude or knowledge in the different courses in, we used ACT and beginning attitude or beginning content knowledge as covariates. We selected the covariates by testing the fit of various models and examining the R^2 values of either a single covariate or a pair of covariates. Insufficient sample sizes (<10) from certain subgroups (all majors in old non-majors courses, non-freshman majors in the new course, and all subgroups in one of the non-majors courses (1214)) them from analysis. Thus in our analysis we compared 1114-old (labeled Old Non-Majors Course), 1304 (labeled Old Majors Course) to 1114-new (labeled New Course Spring 1999, and New Course Spring 2000). Because we were interested in how different subgroups responded to the courses, we focused our analysis on the four-way interaction terms (e.g. Are there differences among the average attitude scores of those male, freshman, non-life-science majors taking Old Majors Course, those taking Old Non-Majors Course, and those taking the New Course?). We only included the data for students who completed the entire beginning and ending surveys and for whom we could obtain ACT scores from the Office of Institutional Research.

We selected the ANCOVA models as follows. We adopted a parallel lines model and used the intercepts and adjusted means (LSMEANS) to compare the treatments when all the slopes of the treatments' regression lines were equal. Otherwise, we used the unequal slopes model and compared treatments at multiple values of the covariate.

Our factorial design was course (3 levels) x sex (2 levels) x major (2 levels) x class standing (2 levels). We had two data sets for the new course (Spring 1999 and Spring 2000); however adding an additional factor (year), increasing the number of course levels, or combining the semesters would further complicate attempts to determine which course was influencing any observed differences. In addition, combining data from the Spring 1999 and Spring 2000 semesters was not possible because it would have resulted in highly uneven sample sizes between the new and old courses. Therefore, we compared scores for 1304 and 1114-old to scores for each semester of 1114-new and the scores for each semester of 1114-new to each other.

Results

Our analysis revealed moderate positive correlations (0.4-0.6) between ACT, beginning attitude or beginning content knowledge, and change in attitude or change in content knowledge. Therefore, because some of the slopes of the treatments' regression lines were significantly different from 0, ANCOVA was appropriate for our analyses as a way to adjust change in attitude and change in content knowledge scores to account for differences in academic ability (ACT) and initial attitude.

We compared the effects of course x sex x major x class standing on changes in attitude scores using single and pairs of covariates. The relationships between individual and pairs of covariates and dependent variables are shown in Table 1. Based on these data, we elected to use ACT and initial attitude as covariates for our analysis of change in attitude and ACT and initial content knowledge as covariates for our analysis of change in content knowledge

Table 1. R^2 values indicating the strength of the relationship between change in attitude and change in content knowledge and the individual covariates and pairs of covariates.

	Dependent Variable	
Covariate	Change in Attitude	Change in Content Knowledge
Initial Attitude	$R^{2} = 0.6232$	$R^{2} = 0.0815$
Initial Content Knowledge	$R^{2} = 0.2689$	$R^{2} = 0.1692$
ACT	$R^{2} = 0.2639$	$R^{2} = 0.0808$
ACT + Initial Attitude	$R^{2} = 0.6388$	$R^{2} = 0.1188$
ACT + Initial Content Knowledge	$R^{2} = 0.3076$	$R^{2} = 0.2607$

During our analysis of changes of attitude scores, we found that the treatment groups' slopes were not all equal for each of the covariates (ACT p=0.0011, initial attitude p=0.0001). We therefore used the unequal slopes model and selected three values of ACT composite scores (21, the minimum required for normal admission at OSU, 25, the mid-point, and 30) for our analysis of the different subgroups (course x sex x major x class standing). We refer to these ACT scores as low, middle and high values for students in these courses. While students with higher ACT composite scores were enrolled, there were too few to reliably use this portion of the model. There was also only a limited sample of attitude scores for the different subgroups at high and low values of ACT. This resulted in extrapolation of initial attitude scores beyond a reasonable range for some subgroups. We therefore chose to compare change in attitude among subgroups only at the average initial attitude score of 48.6.

Our analysis of change in content knowledge indicated that the treatment groups' slopes were equal for one of the covariates, ACT composite score (p=0.5241). We therefore used a parallel slopes model to analyze changes in content knowledge at any ACT composite scores. We judged some of the treatment groups' slopes to be unequal for the other covariate, initial content knowledge (p=0.0898). We therefore adopted an unequal slopes model and compared subgroups using the average students' initial content knowledge score, 25.

Change in Attitude

Freshman Majors

In males (Figure 1.), there was a significant difference between the change in attitude scores in the old majors course and the new course at all ACT levels. Inspection of the data indicates what appears to be continued improvement between the first and second spring semesters that the new course was offered. It also appears that there is no difference among these students at different ACT levels. These students showed the most positive gain in change in attitude culminating in a positive change in attitude at all ACT levels by Spring 2000. In females (Figure 2.), there was a significant difference in attitude scores among courses at medium and high ACT levels. Inspection of the data indicates what appears to be continued improvement between the first and second spring semesters that the new course was offered. There appear to be differences among students with different ACT scores. Those with lower ACT scores (21) did not show a significant change in attitude score in the new course and had a more negative change in attitude in the new course than the other female, freshman, majors. Those with the highest ACT scores had the most negative change in attitude toward biology in the old course, but exhibited a positive change in attitude in the new course.

Freshman, Non-Majors

In males (Figure 3.), there was a significant difference in change in attitude scores among the courses at all ACT levels. Inspection of the data indicates a large difference between the new course and the old courses and what appears to be continued improvement between the first and second spring semesters that the new course was offered. In females (Figure 4.), there was a significant difference among courses at high ACT levels in Spring 1999 and at medium and high ACT levels in Spring 2000. Inspection of the data indicates what appears to be continued improvement between the first and second semesters that the new course was offered. There appear to be differences among students with different ACT scores. Those with higher ACT scores (25, 30), had a more negative change in attitude toward biology in the old course, but exhibited a less negative change in attitude toward biology in the new course.

Non-Freshman, Non-Majors

In males (Figure 5.), there was a significant difference in change in attitude scores among courses at all ACT levels. Inspection of the data indicates a large difference between the new course and the old courses. In females (Figure 6.), there was a significant difference among courses at medium and high ACT levels. Inspection of the data indicates what appears to be continued improvement between the first and second spring semesters that the new course was offered. There appear to be differences among students with different ACT scores. Those with lower ACT scores (21), had a more negative change in attitude in the new course than the other groups and did not show a significant change in score. Those with the highest ACT scores had the most negative change in attitude toward biology in the old courses, but exhibited a positive change in attitude in the new course.

Change in Content Knowledge

Freshman, Majors

In males (Figure 7.), there were no significant differences in change in content knowledge scores between the new and old courses. Based on a visual examination of the data, it appears that students with higher ACT scores have higher change in content knowledge scores in both courses. In females (Figure 8.), while there was a significant decrease in the change in knowledge scores when we compared the old course to the new course in Spring 1999, by the Spring 2000 semester there were no significant differences between the old and new courses. Based on a visual examination of the data, it appears that students with higher ACT scores have higher change in content knowledge scores in both courses.

Freshman, Non-Majors

In males (Figure 9.), there was a significant decrease in the change in knowledge scores between the old and new courses for all ACT levels. Based on a visual examination of the data, it appears that students with higher ACT scores have higher change in content knowledge scores in both courses. It also appears that there was an improvement in change in content knowledge between the Spring 1999 and Spring 2000 students, although it was insignificant. In females (Figure 10.), except for those with high ACT scores in Spring 2000, there was a significant decrease in the change in knowledge scores between the old and new courses for all ACT levels. Based on a visual examination of the data, it appears that students with higher ACT scores have higher change in content knowledge scores in both courses. It also appears that there was an improvement in change in content knowledge between the Spring 1999 and Spring 2000 students, although it was insignificant.

Non-Freshman, Non-Majors

In males (Figure 11.), except for the students with high ACT scores in Spring 2000, there was a significant decrease in the change in knowledge scores between the old and new courses for all ACT levels. Based on a visual examination of the data, it appears that students with higher ACT scores have higher change in content knowledge scores in both courses. It also appears that there was an improvement in change in content knowledge between the Spring 1999 and Spring 2000 students, although it was insignificant. In females (Figure 12.), there were no significant differences between the new and old courses. Based on a visual examination of the data, it appears that students with higher ACT scores have higher change in content knowledge scores in both courses.

Conclusions

Change in student attitudes toward biology

Our change to a more student-centered pedagogy clearly affected students' attitudes toward biology. While our traditionally taught courses were characterized by substantial declines in attitude, this attitude change was moderated in our revised course for almost all student groups, regardless of sex, class standing, starting attitude, or performance on ACT. There was a significant improvement for all males and for females who scored 25 or above on the ACT composite exam. Females who earned low scores on the ACT showed non-significant improvements in their attitudes. Generally, it also appears that attitudes are improving over time. Our results are very consistent with the findings of others.

Gogolin and Swartz (1992) found, as we did, that science majors started with a more positive attitude toward science than did non-majors. They also found, as we did in our old courses, that while non-science majors' attitudes improved at the end of the course, science majors' attitudes declined. In their case, the courses were separate majors and non-majors biology courses taught using a traditional expository lecture format. The non-science majors' course included applications and material considered to be relevant to the students and there were no prerequisite skills or knowledge required for enrollment. The majors' course included topic areas that Gogolin and Swartz considered less stimulating to students. They considered the teaching in the non-major's course more student-oriented while that in the major's course was more subject-oriented.

Sundberg and Dini (1993) reported more positive attitudes toward science among students in the non-majors course than those in the majors' course. They attributed this to the reduced level of detail and greater emphasis on current applications and social relevance in the non-majors' course. When Sundberg and Moncada (1994) restructured their laboratories to place a greater emphasis on inquiry and investigation, the results from their survey of student attitudes indicated that students had mixed responses to the format. While many enjoyed the format of the course, there was a decrease in students' attitudes to science.

Miller and Cheetham (1990) and Goodwin et al. (1991) evaluated the attitudes of major and non-major students enrolled in a biology course that reduced lecture time to a minimum and employed a problem-based, investigative, cooperative-learning approach. While students had initial reservations, their attitudes toward the course were positive by the end. Majors appeared to be more comfortable with the format than non-majors.

Ebert-May et al. (1997) interviewed their students after switching to a cooperative-learning approach to teaching non-majors in a large lecture. Students were much more positive about the learning environment and felt that biology was much less intimidating.

Rogers and Ford (1997) used the same attitude scale that we did when comparing attitudes among students enrolled in majors and non-majors courses. Once again while the non-majors had a significant increase in attitude toward biology, the students' attitudes in one of the majors courses became more positive, while those in another majors course became more negative.

Ebenezer and Zoller (1993) looked at the impact of a constructivist approach to teaching in secondary schools and found no change in attitudes that could be attributed to the change in approach. However, most students reported that their classes involved note taking, textbook, and individual rather than group experiments. Few reported that teachers used the students' ideas or computers in their classes. The researchers concluded that the teaching-style practiced was the determining factor affecting student attitude.

Thus it appears that restructuring a course to include introducing concepts within a relevant context, more cooperative learning, more inquiry, more problem-based learning and more investigations in the laboratory is beneficial to both majors and non-majors. We are now actually finding increases in attitudes toward science among most groups. Most notably our biology majors, a group whose attitudes have been negatively affected by the traditional expository teaching approach at our institution and elsewhere, have been positively influenced by our revised approach. We agree with Sundberg and Dini's (1993) conclusion that majors and non-majors both need to be taught in a manner other than the traditional expository style with its emphasis on memorization of facts and terminology.

That certain groups are not as positively affected as others still presents a challenge to us as we seek to provide scientific literacy to all. In particular, we note that women with low ACT scores did not show a significant change in attitude. While we cannot be sure that this is actually a reflection of the situation (they do show a positive trend, just not a significant one), it may be consistent with findings of Von Secker and Lissitz (1999) which supported the conclusion that females who were low achievers did not benefit from student-centered practices and those of Meese and Jones (1996) which supported the conclusion that only low-ability females were less motivated than males to learn. Both of these studies were at the pre-college level. Because we did not assess motivation, self-confidence or learning styles, it is impossible to speculate how these factors influence attitudes among these students.

One of the most striking differences we saw between student- and teacher-centered instruction was among female, life-science majors whose ACT scores were high. If, as Seymour and Hewitt (1997) suggest, female students are more likely to abandon the sciences as a major than their male counterparts, because of the competitive nature of many science courses, poor teaching, a lack of opportunities to participate or the inability to see connections to their personal lives, then the use of inquiry and collaboration should help to balance the gender gap as students progress into upper-division science courses.

Change in content knowledge

One of the concerns in this change in teaching style was that the majors would not be learning content as well. By the last semester of our study, all of our majors were performing as well in the new course as in the old on the content knowledge portion of our survey. For non-majors the results are not as clear. While some groups performed equally well, others appeared to decline slightly. To interpret these results, there are several important issues to consider.

First, the test of content knowledge in no way affected students' course grades; therefore students may not have the strong motivation to do well. In fact, time spent working carefully on the questions detracted from lab time. The negative change in content knowledge may reflect students' lack of motivation to do well on the end of semester survey. Secondly, the survey was administered during the last lab period and students who were satisfied with their grades often elected to skip the last lab.

We would also argue that instruction which emphasizes problem-solving skills and process of science methods is difficult to assess with the standardized instrument available, and improvements in students' abilities in these areas was not adequately assessed by the instrument used. Ebert-May et al. (1997) also found that non-majors' content knowledge did not increase when measured by a comparable instrument. Much emphasis on the exam is still on factual recall. Students performed well on our regular course exams, which have greater emphasis on process and application. Thus, it may be that majors are able to learn the needed vocabulary for their future science courses while developing better process and application skills. Côté and Levine (2000) found that personal motivation to learn was a significant factor in determining student ability to achieve true understanding of content. Perhaps majors have a higher personal motivation to learn and recall facts and vocabulary. Non-majors may not have this motivation, and thus do not learn and recall facts and vocabulary unless they know they will be required to do so. Additionally, students whose reasoning skills are less developed, as measured by ACT scores, may still be struggling in an environment that requires students to derive concepts from observations rather than directly from lecture. Both von Secker and Lissitz (1999) and Gogolin and Swarz (1992) concluded that a more structured teaching style might benefit these students. We suggest that more direct attention to these students may be important in helping them gain the most from this style of teaching. New assessment techniques are needed that can better assess process and application skills as well as a longer term study that assesses retention of material.

We conclude that the new course, with its use of multimedia, collaborative learning, and inquiry-oriented instruction in lecture and laboratory provides a positive environment for learning and contributes to improving students' attitudes toward biology. Thus, this style of instruction should help promote both general science literacy and the continued pursuit of science as a career.

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Figure 1. Change in Attitude in Male, Freshmen, Majors

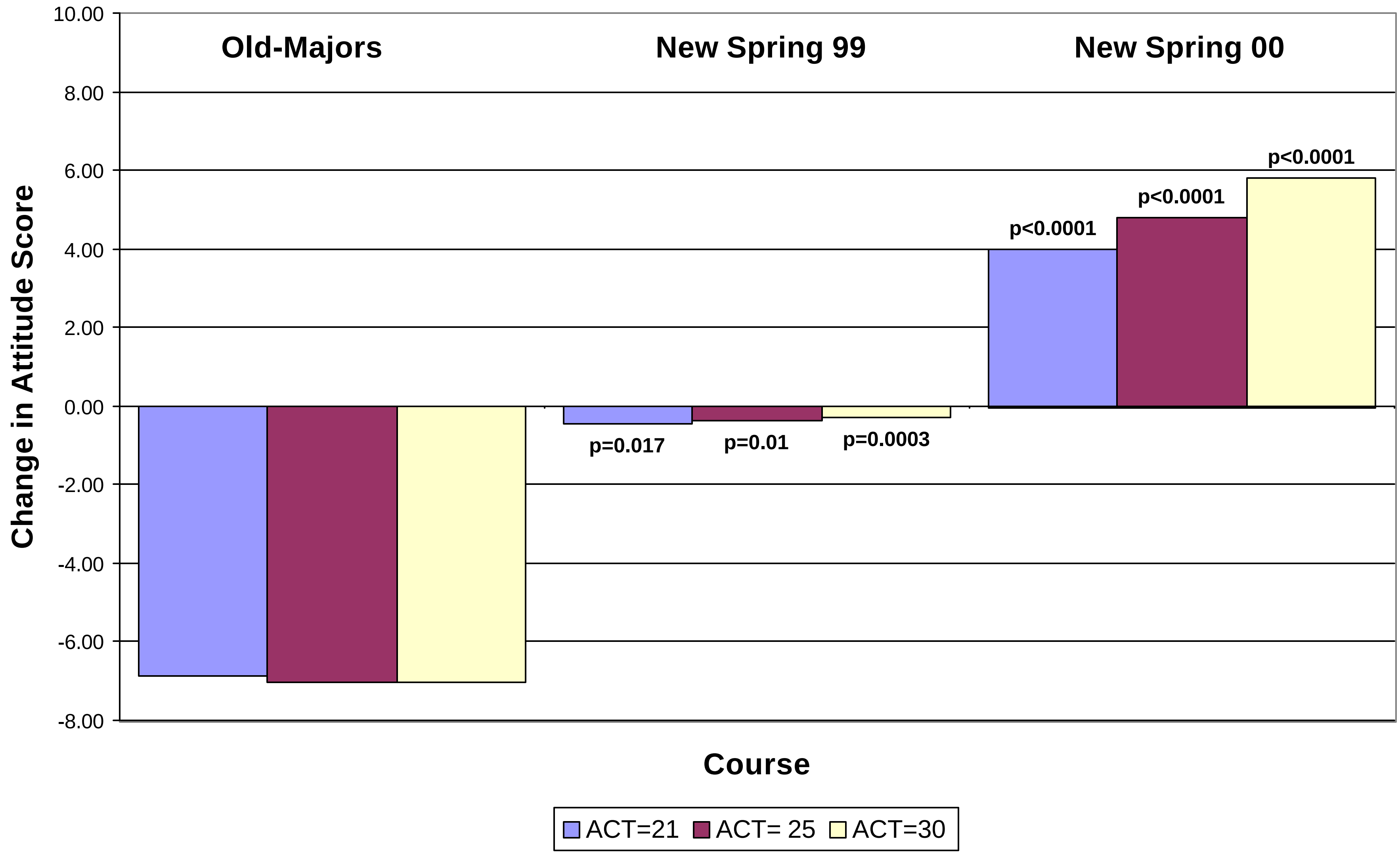


Figure 2. Change in Attitude in Female, Freshmen, Majors

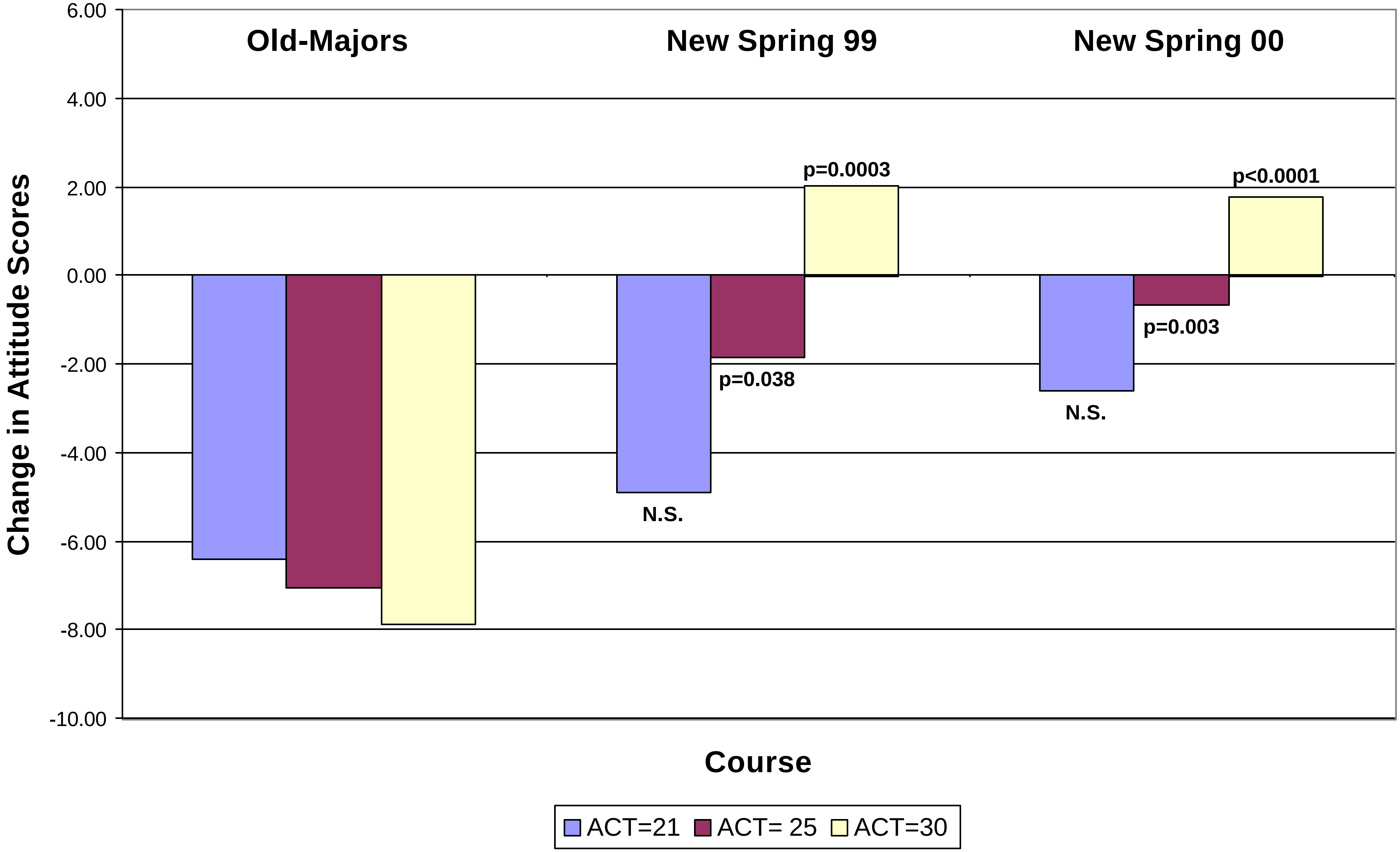


Figure 3. Change in Attitude in Male, Freshmen, Non-Majors

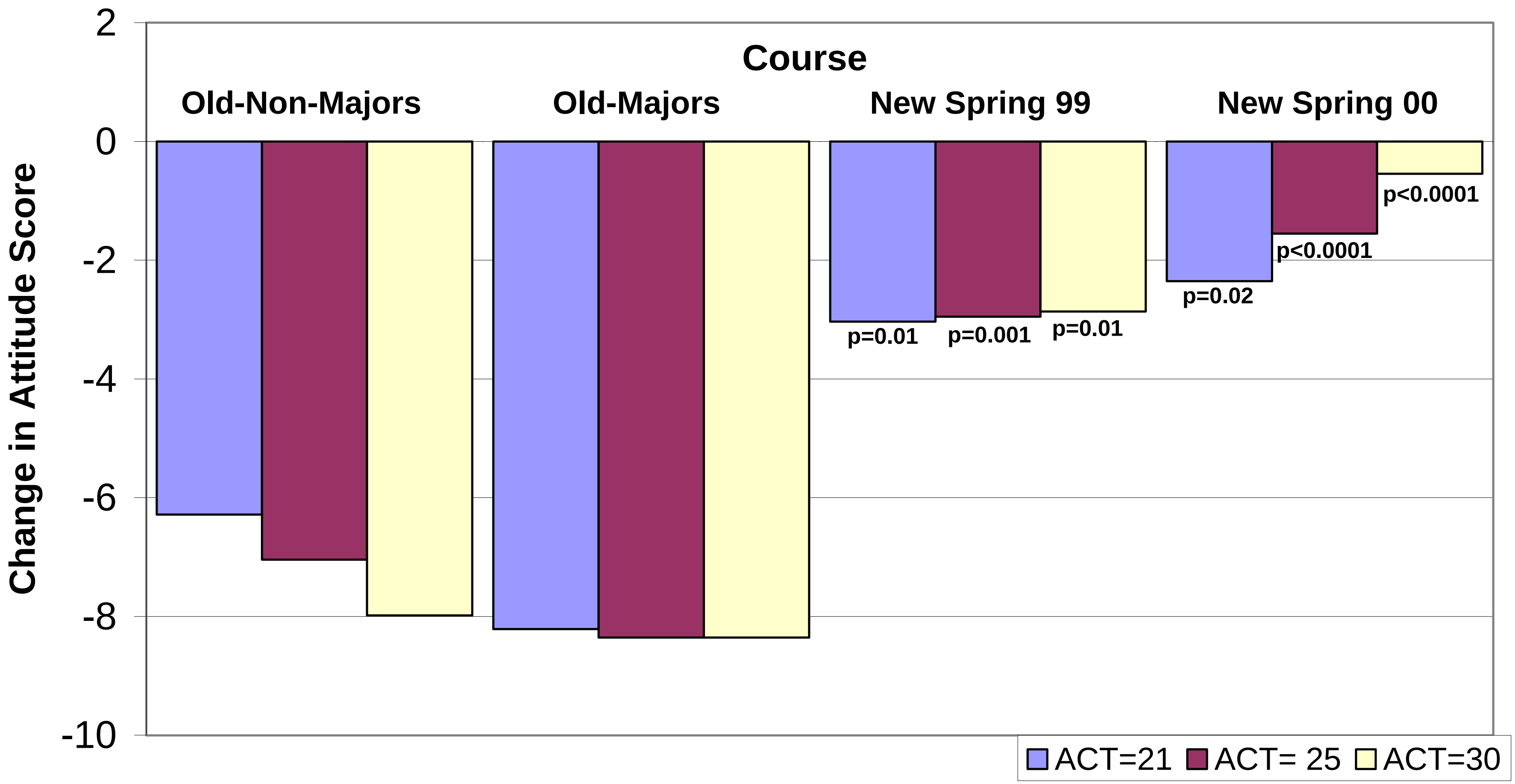


Figure 4. Change in Attitude in Female, Freshmen, Non-majors

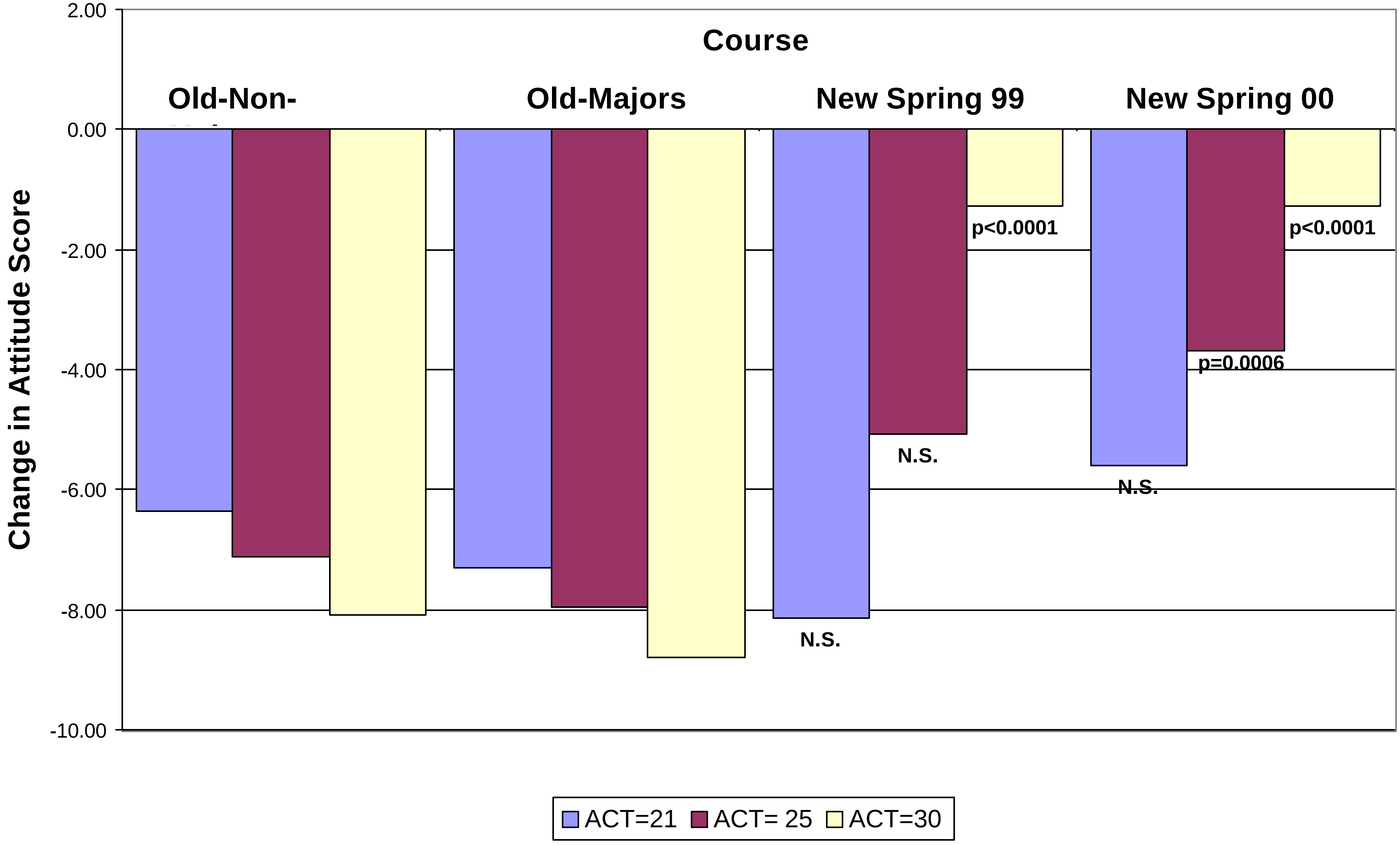


Figure 5. Change in Attitude in Male, Non-Freshmen, Non-majors

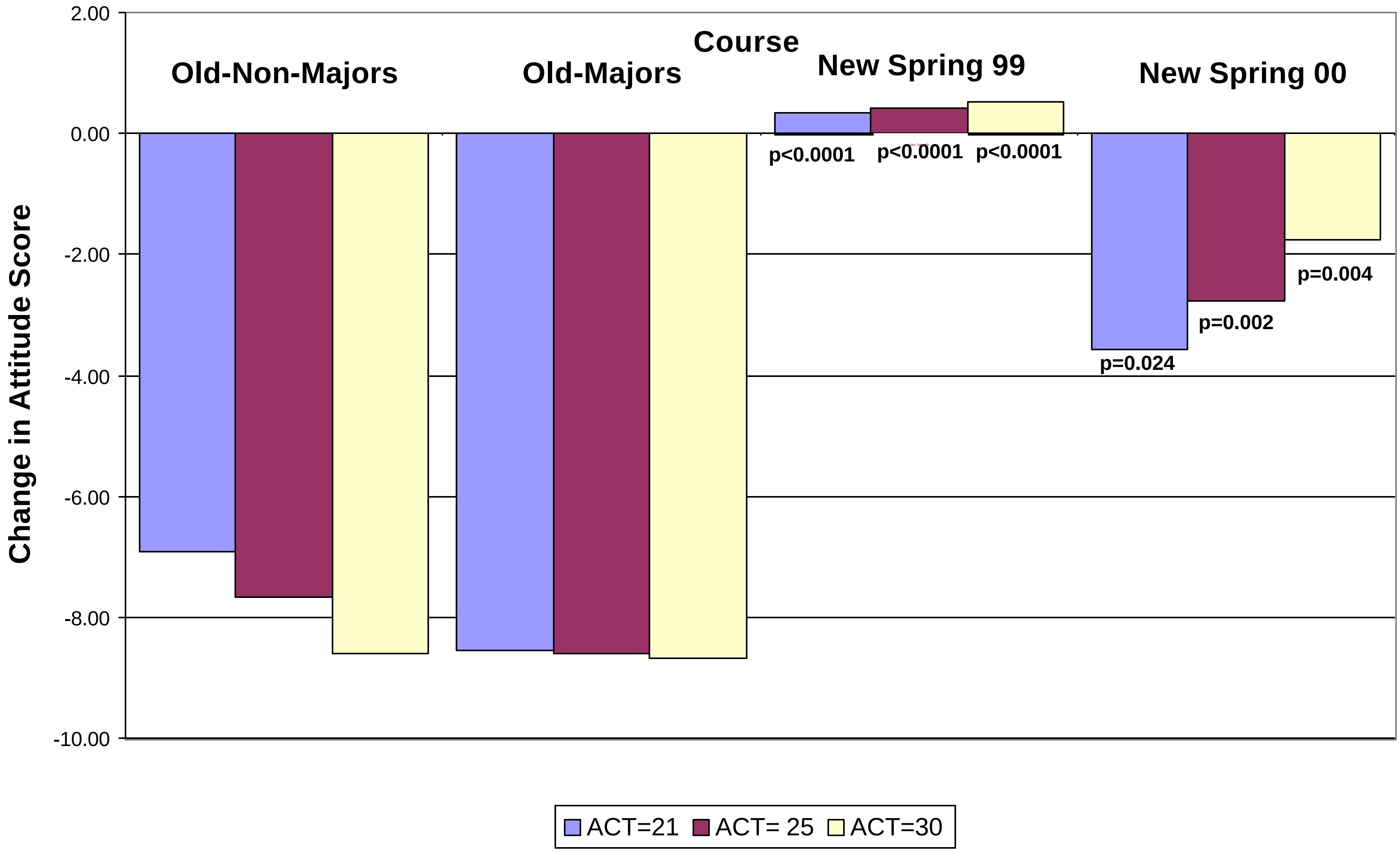


Figure 6. Change in Attitude in Female, Non-Freshmen, Non-majors

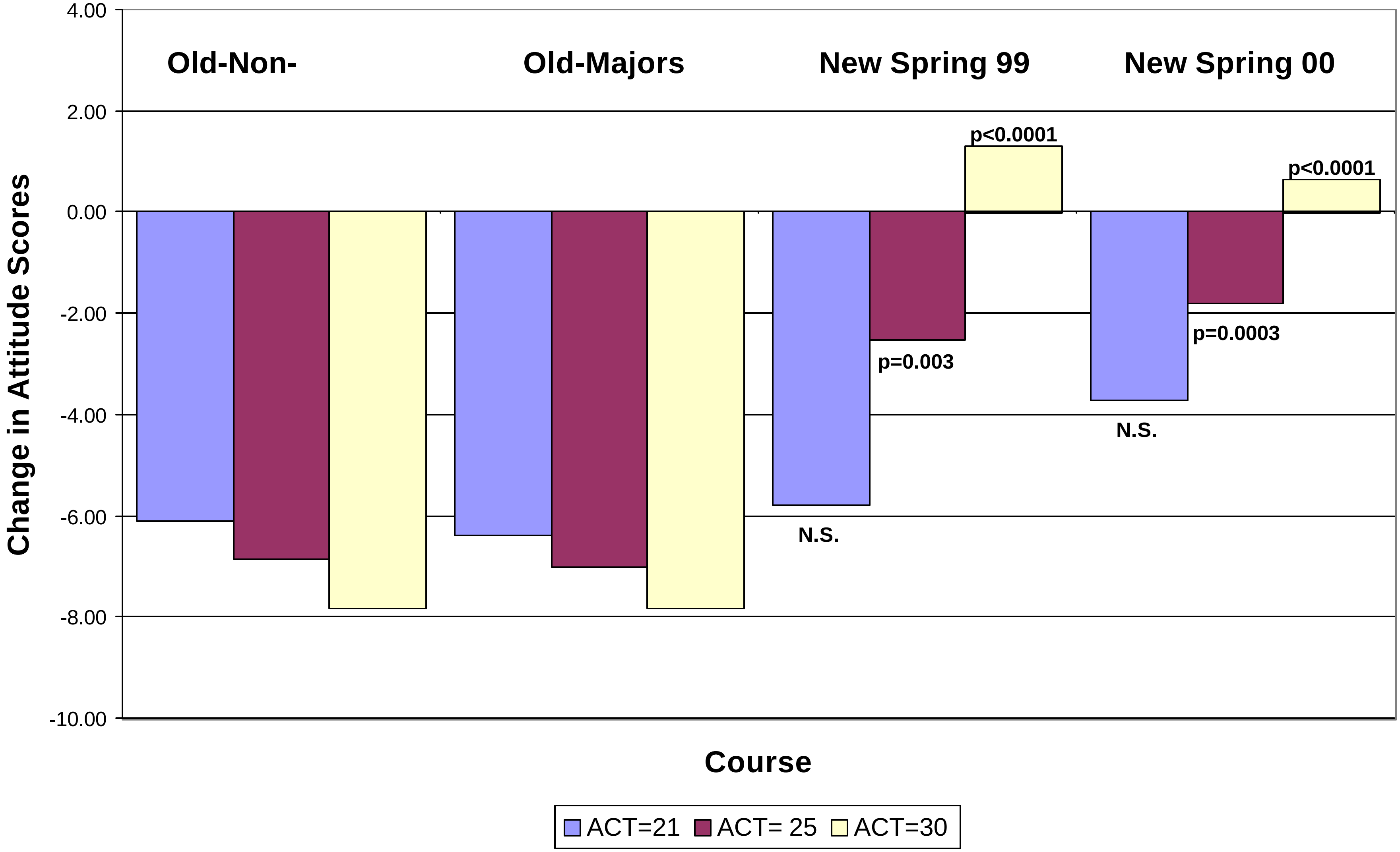
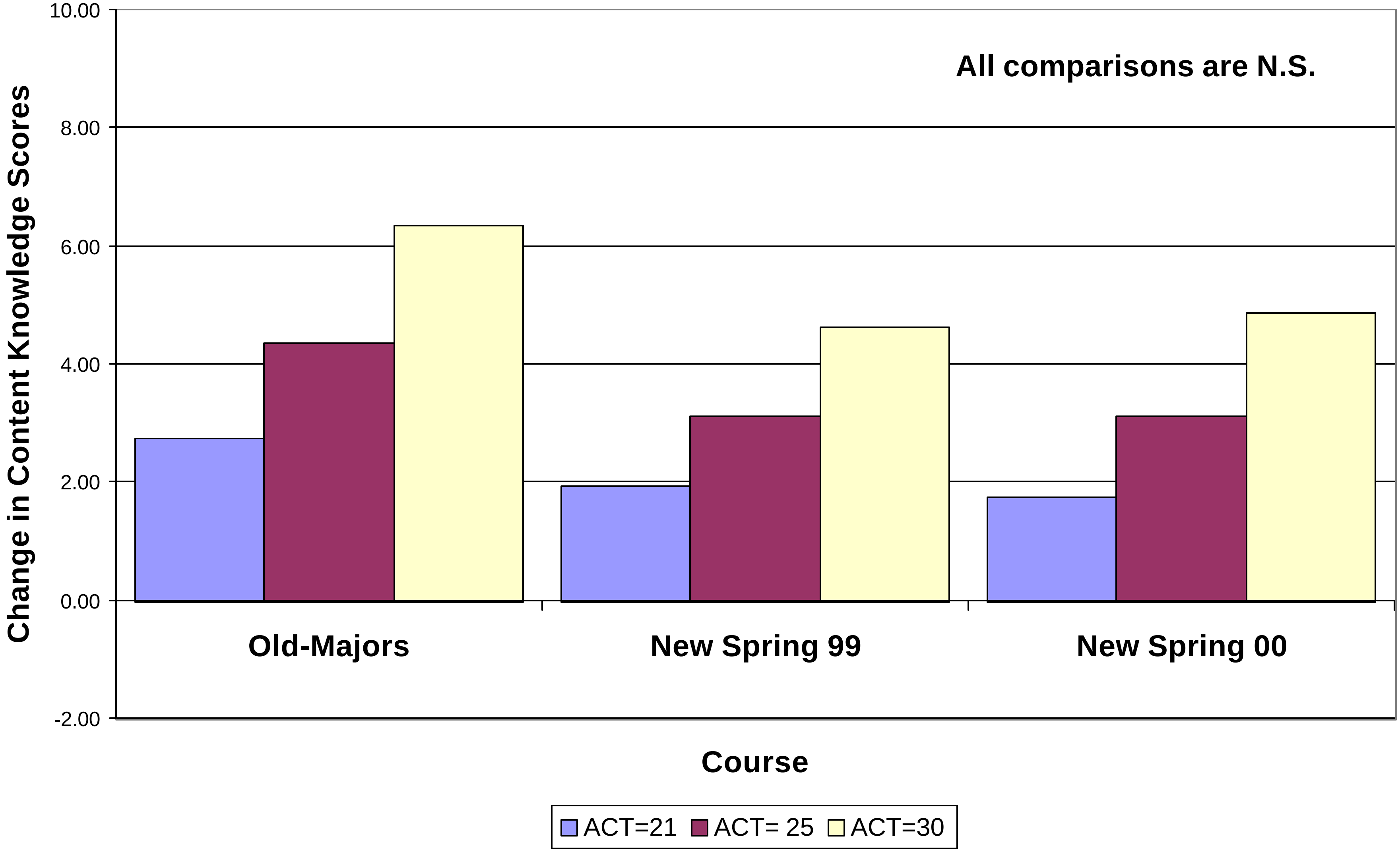


Figure 7. Change in Content Knowledge in Male, Freshmen, Majors



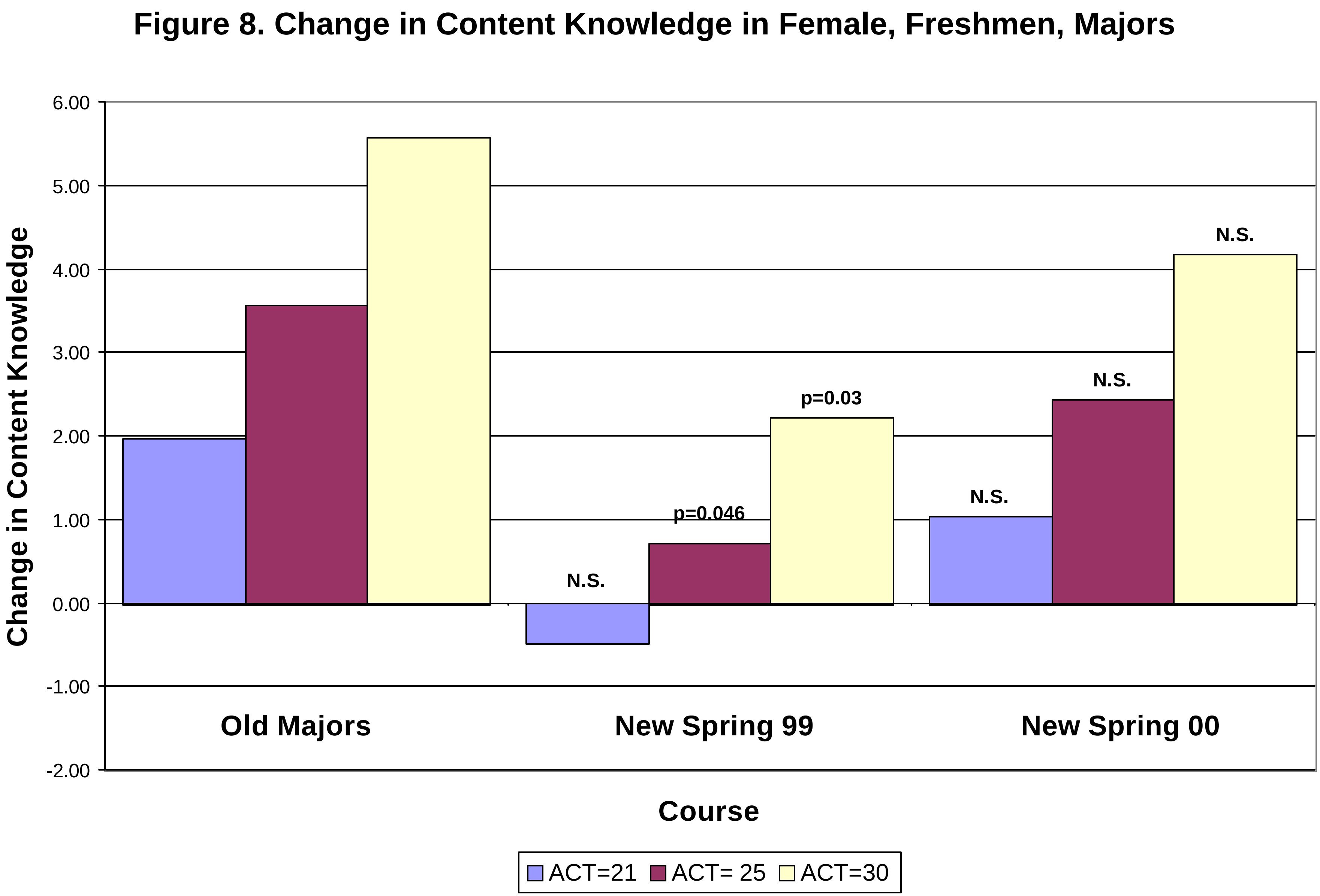


Figure 8. Change in Content Knowledge in Female, Freshmen, Majors
Change in Content Knowledge
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
N.S.
p=0.046
p=0.03
N.S.
N.S.
N.S.
Old Majors
New Spring 99
New Spring 00
Course
ACT=21
ACT= 25
ACT=30

Figure 9. Change in Content Knowledge in Male, Freshmen, Non-majors

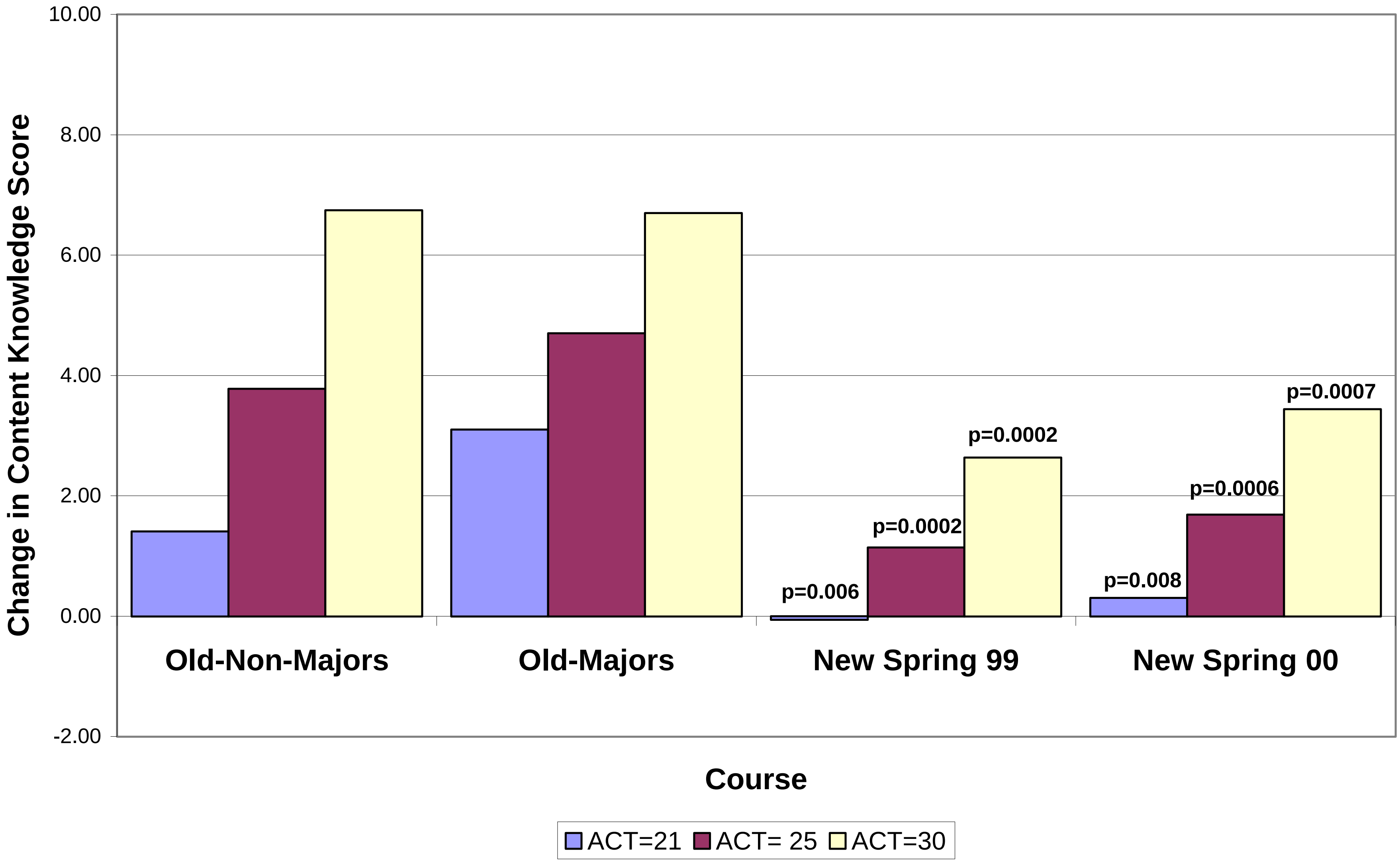


Figure 10. Change in Content Knowledge in Female, Freshmen, Non-majors

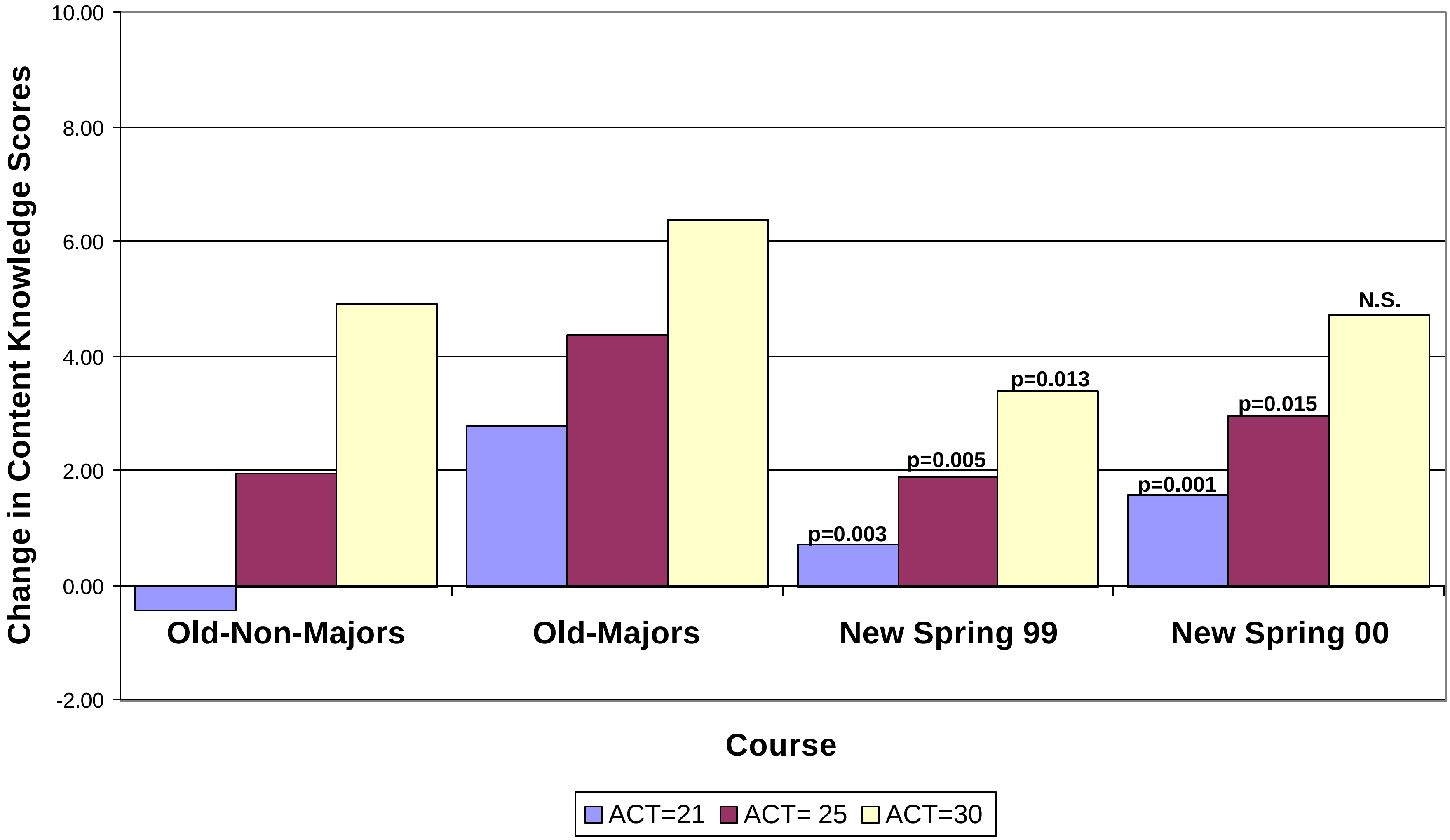


Figure 11. Change in Content Knowledge in Male, Non-freshmen, Non-majors

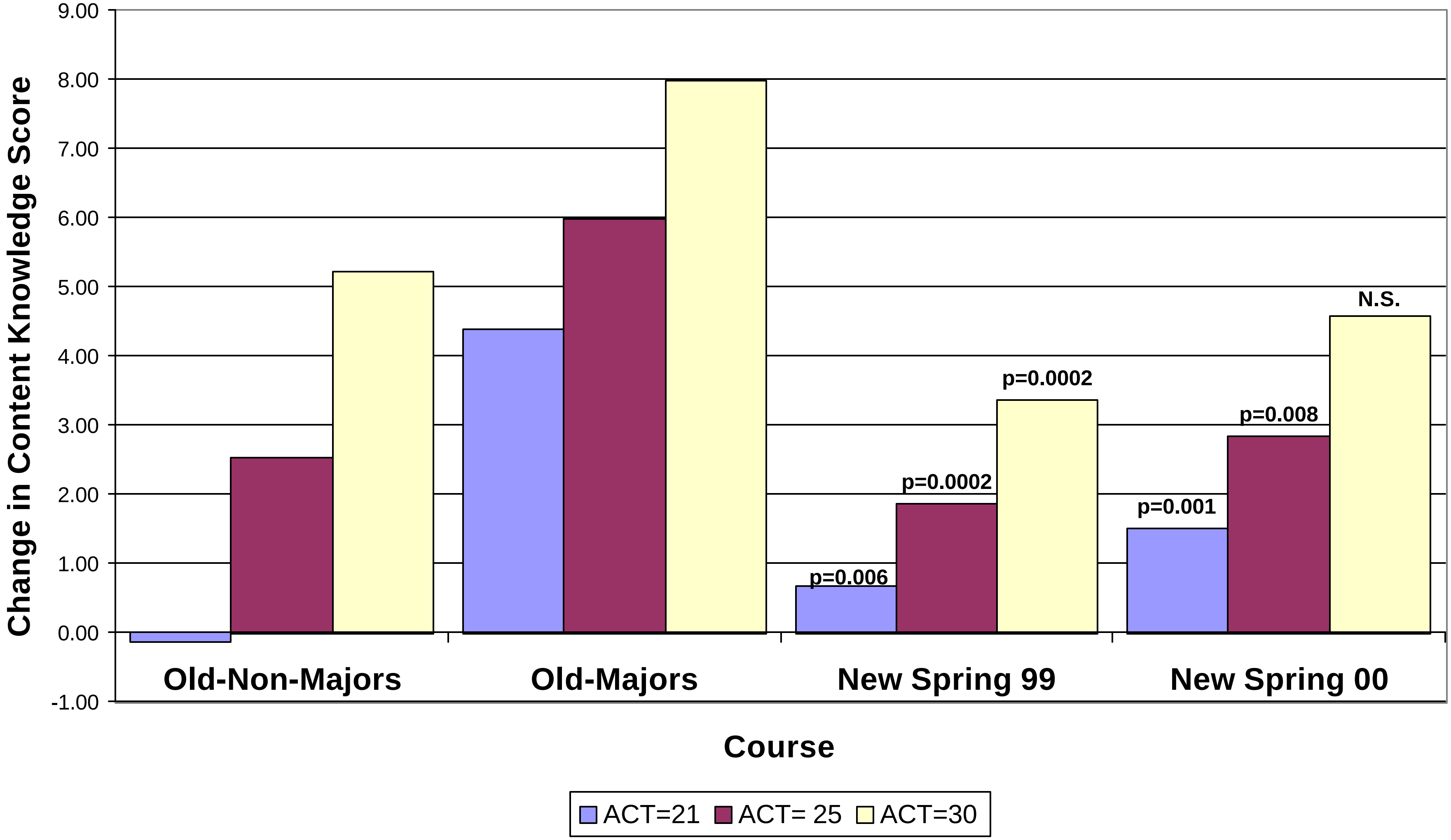


Figure 12. Change in Content Knowledge in Females, Non-Freshmen, Non-majors