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RESEARCH ARTICLES

Longitudinal Assessment of Critical Thinking in Pharmacy Students

Donald R. Miller, PharmD

College of Pharmacy, North Dakota State University

Objectives. The purpose of this study was to describe changes in critical thinking ability and disposition over a 4-year Doctor of Pharmacy curriculum.
Methods. Two standardized tests, the California Critical Thinking Skills Test (CCTST) and California Critical Thinking Dispositions Inventory (CCTDI) were used to follow the development of critical thinking ability and disposition during a 4-year professional pharmacy program. The tests were given to all pharmacy students admitted to the PharmD program at the College of Pharmacy of North Dakota State University (NDSU) on the first day of classes, beginning in 1997, and repeated late in the spring semester each year thereafter.
Results. Increases in CCTST scores were noted as students progressed through each year of the curriculum, with a 14% total increase by graduation ($P< 0.001$). That the increase was from a testing effect is unlikely because students who took a different version at graduation scored no differently than students who took the original version. There was no increase in CCTDI score.
Conclusion. The generic critical thinking ability of pharmacy students at NDSU's College of Pharmacy appeared to increase over the course of the program, while their motivation to think critically did not appear to increase.

Keywords: critical thinking, assessment, outcomes, curriculum

INTRODUCTION

Critical thinking is a widely used term that refers to skills in applying, analyzing, synthesizing, and evaluating information.[1] The ability to think critically is frequently listed as a desirable outcome of undergraduate and professional education,[1] and is one of the educational outcomes established by the Center for Advancement of Pharmaceutical Education (CAPE) of the American Association of Colleges of Pharmacy.[2] Unfortunately, there is no published research on whether pharmacy curricula actually improve critical thinking in a meaningful way. If we could establish that significant increases are possible, schools of pharmacy could institute appropriate educational strategies. On the other hand, a lack of positive results would suggest that scarce educational resources should be redirected to more fruitful use.

Corresponding Author: Donald R. Miller, PharmD. Mailing Address: Department of Pharmacy Practice, North Dakota State University, 123 Sudro Hall, Fargo, ND 58105-5055. Tel: 701-231-7941. Fax: 701-231-7606. E-mail: Donald.Miller@ndsu.nodak.edu.

One problem that impedes study of critical thinking (CT) is widely divergent definitions of the term. Because of the complexity of defining and measuring CT, numerous definitions exist. It has been described simply as "thinking about thinking."[3] A definition by Robert Ennis is "reasonable and reflective thinking that is focused on what to believe or what to do."[4] A construct of critical thinking based on a 1990 American Psychological Association Delphi Report defined it as purposeful, self-regulatory judgment that gives reasoned consideration to context, evidence, concepts, methods and standards in deciding what to believe or what to do.[5] Most would agree that CT is not a linear or simple process, but involves reasoned and reflective consideration of evidence in a particular context in order to make a judgment. It also means being open-minded, and willing to put aside personal biases.[6] Unfortunately, confusion arises because many authors use more specific definitions or confine their interest to very specific skills.[1]

The relevance of critical thinking can be seen in the context of a practitioner's required intellectual skills for competent practice. Perry hypothesized that

students move through successive stages of intellectual development, from *dualism* to committed *relativism*.[7] The earliest or simplest stage of development is *dualist*. Such students see the world in absolutes, as right or wrong, black or white. They believe authorities know the right answers and it is their job to give those answers to students, who should regurgitate them unaltered. These students consider learning strictly as a quantifiable product, not as a process. Ambiguity is seen as a lack of knowledge that will eventually be resolved. Many college students, including pharmacy students, come to us at this level of development.

According to Perry, *multiplicity* is a higher stage of critical thinking reached when students realize that equally credible people may disagree. They conclude that there is no right answer and everyone is entitled to their opinion. *Relativism* is reached when students understand that the right answers may be relative; they depend on the situation and evidence to back them up. Reasoning and critical thinking must be used to understand other positions. *Committed relativism* is the highest stage, where students are willing to commit themselves to ideas and positions, based upon defensible logic and reasoning. Our goal as educators should be the production of pharmacists at least at the level of relativism, since that seems essential for rendering complex professional judgments about drug therapy.

The California Critical Thinking Skills Test (CCTST) is a challenging, discipline-neutral measure of one's actual cognitive skills in critical thinking.[5] It is a standardized and validated 34-item, multiple choice test which targets those core critical thinking skills regarded to be essential elements in a college education. There is only one correct answer for each question and one point is given for each correct answer. The CCTST also reports 5 subscales: analysis, evaluation, inference, deductive reasoning, and inductive reasoning. The CCTST test manual describes normative scores in a large sample of college students, and provides evidence for content, construct, and criterion validity.

The CCTST uses a construct of critical thinking based on the 1990 American Psychological Association Delphi Report, which describes the interactive skills of interpretation, analysis, inference, evaluation, and explanation. Other standard tests exist that use somewhat different working definitions of critical thinking and different test strategies. An older, frequently used test, is the Watson-Glaser Critical Thinking Appraisal.[8] Like the CCTST, it is a multiple-choice tool with text-based questions. However, it uses a more limited response format than the CCTST, as Watson-Glaser asks test takers to evaluate whether each purported conclusion must be true, is probably true, is probably not true, or must be false. No consensus exists on the best test. Results with one test cannot be assumed to be equivalent to those of other tests because the tests use somewhat different constructs. An individual's results on the CCTST correlate moderately well (0.405 to 0.544) with the same individual's results on the Watson-Glaser test, thus establishing concurrent validity between tests.[9] Reliability of the CCTST was established by Kuder-Richardson coefficients for internal consistency of about 0.70.[5]

Associated with the CCTST is the California Critical Thinking Dispositions Inventory.[10] Abilities have been described as an integration of knowledge, skills, and attitudes. Thus, the disposition to think critically should help a person actually attain the skills, while tendencies toward intolerance and apathy would be counterproductive. The CCTDI is a measure of one's personal disposition to prize and to use critical thinking in one's affairs. Students are asked to indicate agreement or disagreement with 75 different statements along a 6-point Likert scale. The CCTDI has 7 subscales that contribute equally to the overall score. They are truth seeking, open mindedness, analyticity, systematicity, confidence in critical thinking, inquisitiveness, and cognitive maturity.

There are limited data on how critical thinking skill relates to pharmacy student performance. One group of investigators found the Watson-Glaser Critical thinking Test correlated with pharmacy student grade point average (GPA), but not with clinical problem-solving skills.[11] Others have reported a positive correlation between CCTST score and performance in a Pharmacy Health Care and Behavior class,[12] and between CCTST score and clerkship success.[13] Duncan-Hewitt found an essay test of problem-solving ability in pharmacy correlated very well with the CCTDI but there was no correlation with the CCTST.[14]

The purpose of this study was exploratory and descriptive in nature. Research objectives were to (1) determine if general critical thinking skills or disposition, as defined by Facione and Facione,[5] and assessed by the CCTST and CCTDI, would improve over the 4-year professional curriculum at North Dakota State University, (2) to determine whether any such changes were related to student demographic characteristics.

METHODS

Data were collected yearly for all doctor of pharmacy students who started the curriculum from 1997 to 2001. Approval was obtained from the Institutional Review Board. The CCTST was given to all incoming

Table 1. Mean Total Scores By Year of Admission and Year in Professional Program

	1997	1998	1999	2000	2001
Mean CCTST Scores (SD)					
Admission	18.03 (4.27)	18.26 (4.45)	18.19 (3.72)	17.31(4.41)	16.75 (4.15)
	n = 60	n = 60	n = 62	n = 64	n = 73
End P1 Year	19.67 (4.08)	18.81(5.07)	18.51 (3.52)	18.68 (3.84)	TNA
	n = 52	n = 53	n = 53	n = 50	
End P2 Year	19.64 (4.26)	19.86 (4.66)	19.90 (3.03)	19.56 (4.06)	TNA
	n = 53	n = 59	n = 29	n = 63	
End P3 Year	20.93 (3.99)	21.33 (4.61)	TNA	TNA	TNA
	n = 57	n = 45			
End P4 Year	20.35 (4.41)	21.71 (4.82)	TNA	TNA	TNA
	n = 49	n = 58			
Mean CCTDI Scores (SD)					
Admission	307.7 (24.2)	305.8 (22.6)	301.1 (22.3)	301.6 (24.5)	294.4 (25.3)
	n = 60	n = 60	n = 62	n = 64	n = 73
End P4 Year	303.8 (25.7)	300.4 (24.4)	TNA	TNA	TNA
	n = 51	n = 58			

CCTST = California Critical Thinking Skills Test, SD = standard deviation, n = number, P1 = first professional year, P2 = second professional year, P3 = third professional year, P4 = fourth professional year, CCTDI = California Critical Thinking Dispositions Inventory, TNA = test not administered to this group

students during fall orientation, beginning in 1997, and again near the end of each spring semester (In 2002 it was given only to the second and fourth year professional class at the end of the semester).

An issue arising from yearly testing is whether students improve their test scores from memorizing or becoming more familiar with the questions. Fortunately, the influence of familiarity and testing effects can be measured by using a second version of CCTST. The test comes in 2 statistically equivalent forms, form A and form B (a newer form 2K, that includes visual and quantitative items is also available). The two versions of the CCTST are different, but parallel in structure and difficulty. Form A was used for all tests except that fourth professional year students taking their final test were randomly divided into 2 groups, one taking form A and the other form B.

Because previous experience with this instrument had shown that disposition changes minimally over time, data on this outcome were collected only at admission and on graduation. This study used an observational pretest-posttest design. The same curriculum was in place throughout the period of this study. (A list of the courses included in the curriculum is available from the author by e-mail request.) The curriculum was assumed to be the independent variable, while CCTST scores and its subscales, and the CCTDI scores and its subscales, were considered dependent variables. Demographic variables including, age, sex, prior baccalaureate degree, admission Pharmacy College Admissions Test (PCAT) score, admission GPA, and prior critical thinking course were treated as additional independent variables. Admission GPA was defined as the grade point average for all core prepharmacy courses as used for admission decisions, while pharmacy GPA was the grade point average for all courses in the professional curriculum. Pearson product-moment correlations were used to examine correlations between variables. Paired t tests were used to compare admission and graduation scores (both overall and subscales) on the CT tests, while independent t tests were used to compare demographically defined subgroups and versions A and B of the CCTST. The a priori level of statistical significance was 0.05. All statistical analysis was done with Statgraphics Plus for Windows (Manugistics, Rockville, MD) software.

RESULTS

Class Data 1997-2001

Table 1 describes data according to the class that students were in at the time of the test. Yearly testing was done to find out if the bulk of any increase oc-

Table 2. Demographic Statistics of Graduated Students

Variable	N	Mean (SD)	Frequency
Gender	102		
Male			31
Female			71
Age on admission (years)	102	21.9 (4.3)	
Race	102		
White			94
Asian			3
Native American			5
Admission GPA	102	3.61 (0.25)	
Pharmacy GPA	102	3.51 (0.35)	
Admission PCAT Score	102	35.70 (8.0)	
Previous CT course	98		
Yes			7
No			91
Prior Baccalaureate Degree	99		
Yes			10
No			89

N = number, SD = standard deviation, GPA = grade point average, PCAT = pharmacy college admissions test, CT = critical thinking

curred during 1 year of the curriculum. The number of students tested was not consistent because some were unavailable on the day of the test, and some students dropped back a year from their original cohort due to poor grades. The average CCTST score on admission was consistently near 18 out of a possible 34. This is well above the average of 16 points for general undergraduate college students (of all class standings) reported in validation studies, and at about the 75th percentile based on the test's validation samples. The 2000 cohort started slightly lower but has caught up. The 2001 cohort started lower yet, but data were not collected at the end of their first professional year. For each class, a clear and consistent trend toward increased scores is seen, and the data suggest a steady increase throughout. The average admission disposition score was just above 300, although a trend of decreasing admission scores was seen. No significant change in CCTDI occurred.

Data for Graduated Students

The 1997 and 1998 admission cohorts consisted of 120 students (60 in each class). Baseline data were available for all, but final data were available for just 102 of them. Of the 18 students admitted in 1997 or 1998 but not included, one student had dropped out of pharmacy, 5 had not yet graduated by spring 2002, and 12 were not available on the day of final testing. The 18 students with missing data had an average baseline CCTST of 16.61 and CCTDI of 306.6. However, the 6 students who had not graduated had average admission scores of 14.67 and 288 respectively. By confining inferential analysis to students for whom complete data are available, data could be analyzed with paired comparisons. This may have actually hurt the improvement in the cohort, since lower scoring students have the greatest opportunity to show improvement. The demographic statistics of the 102 students with complete data are described in Table 2.

The gains in CCTST made by our students are summarized in Table 3. The overall score increased by 2.64 points or 14% ($P < 0.001$), and statistically significant increases occurred in all subscales as well. The largest improvements came in the evaluation and induction subscales. The range of CCTST scores on admission was 8 to 29 and at graduation was 10 to 32. The admission and graduation CCTST scores were highly correlated with each other (Table 4). The amount of change in CCTST score was related to both initial and final disposition to think critically.

The CCTST scores and the increase in CCTST did not differ by demographic variables listed in Table 2, with a few exceptions. Both initial and final CCTST scores correlated with admission PCAT score ($r = 0.50$ and 0.52 respectively) (Table 4). Initial CCTST scores, but not final CCTST scores, correlated with age. GPA on admission correlated with both initial and final CCTST scores. Pharmacy GPA tended to correlate positively with initial and final CCTST, but not significantly at the $p = 0.05$ level. Seven students reported

Table 3. Changes on CCTST and Subscales for Graduated Students (N=102)

CCTST Subscale (possible range)	Admission(SD)	Graduation(SD)	Difference*
Total (1-34)	18.32 (4.2)	20.96 (4.7)	2.64 (14%)
Analysis (1-9)	4.67 (1.32)	5.34 (1.41)	0.68 (14%)
Evaluation (1-14)	6.88 (2.45)	8.24 (2.58)	1.35 (20%)
Inference (1-11)	6.77 (1.75)	7.38 (1.92)	0.61 (9%)
Deductive Reasoning (1-16)	9.06 (2.56)	9.89 (2.80)	0.83 (9%)
Inductive Reasoning (1-14)	7.51 (2.18)	8.97 (2.35)	1.46 (19%)

* all differences statistically significant at $P < 0.001$
CCTST = California Critical Thinking Skills Test, SD = standard deviation

Table 4. Pearson Correlation Matrix (N=102)

	Age	PCAT	GPA-Ad	GPA-Ph	CCTDI-Ad	CCTDI-F	CCTST-Ad	CCTST-F	CCTST-Ch
Age	1.00	0.18	0.08	0.03	0.13	0.09	0.24*	0.05	-0.22*
PCAT		1.00	0.23*	0.02	0.03	-0.12	0.52*	0.50*	0.05
GPA-Ad			1.00	0.41*	0.08	-0.08	0.29*	0.21*	-0.07
GPA Ph				1.00	0.04	0.04	0.17	0.04	-0.15
CCTDI-Ad					1.00	0.57*	-0.01	0.15	0.20*
CCTDI-F						1.00	-0.12	0.06	0.22*
CCTST-Ad							1.00	0.69*	-0.28*
CCTST-F								1.00	0.50*
CCTST-Ch									1.00

*$P < 0.05$, PCAT = pharmacy college admission test score, GPA-Ad = admission grade point average, GPA-Ph = pharmacy grade point average, CCTDI-Ad = admission California Critical Thinking Dispositions Inventory, CCTDI-F = final California Critical Thinking Dispositions Inventory, CCTST-Ad = admission California Critical Thinking Skills Test, CCTST-F = final California Critical Thinking Skills Test, CCTST-Ch = change in California Critical Thinking Skills Test

taking a prior course in critical thinking, although the type of course was not defined or verified. Students who had taken a course did not have higher CCTST or CCTDI scores. Their mean admission CCTST score was 16.29 versus 18.46 for other students, and their mean admission CCTDI score was 299.7 versus 306.5 for other students. The same trend was seen for final CCTST and CCTDI scores.

There was no significant difference between the scores of graduates taking version A and those taking version B. For the 1997 cohort, 22 students who took version A scored a mean of 19.64 while 27 students who took version B scored 20.93 ($P = 0.31$). For the 1998 cohort, 28 students who took version A scored a mean of 20.61, while 30 students who took version B scored a mean of 22.73 ($P = 0.09$). Therefore, the improvement in CCTST scores appeared to be related to increased ability rather than to a testing effect.

The *disposition* to think critically for graduates, as judged by CCTDI scores in Table 5, was very typical of college students in general, mildly positive, and did not increase during the curriculum. CCTDI scores ranged from 260 to 383 at admission and from 234 to 375 at graduation. There was no correlation between CCTDI and GPA, age, sex, or any other demographic variable.

Scores on the 7 CCTDI subscales are clearly positive if over 40; with scores of 31 to 39 indicating ambivalent attitudes, and those over 50 indicating strongly positive attitudes.[10] Data for these students showed a generally positive disposition on all subscales except for "truth seeking," which is ambivalent. Inquisitiveness was the strongest disposition. However, no significant changes were found between any mean subscale scores over time.

DISCUSSION

The current data indicate that substantial gains in CT ability occurred during the pharmacy curriculum. Validation studies on the CCTST placed the modal score for college undergraduate students at 16, with no difference by year of college.[5] The average admission score for our students puts them at the 75th percentile, and their graduation score puts them at the 90th percentile for college students.[5] The trend toward lower starting scores on both CCTST and CCTDI in 2000 and 2001 may reflect a less competitive pool of stu-

Table 5. Changes in CCTDI and Subscales for Graduated Students

CCTDI Subscale (possible range)	Admission (SD)	Graduation (SD)	Difference
Total (70-420)*	306.6 (23.1)	302.8 (25.3)	- 3.8
Truth Seeking (10-60)	37.28 (6.05)	38.17 (4.88)	0.89
Open Mindedness (10-60)	43.95 (4.58)	42.00 (5.62)	0.05
Analyticity (10-60)	44.96 (4.42)	44.38 (4.55)	-0.58
Systematicity (10-60)	44.35 (5.45)	43.82 (5.42)	0.53
CT Confidence (10-60)	44.41 (4.94)	43.79 (5.20)	-0.62
Inquisitiveness (10-60)	48.30 (4.84)	46.03 (5.86)	-2.27
Cognitive Maturity (10-60)	43.49 (5.88)	43.95 (5.15)	0.46

*neutrality is a score of 245 out of 420

CCTDI = California Critical Thinking Dispositions Inventory, SD = standard deviation, CT = critical thinking

dents applying to the professional program in those later years, as their admission GPA and PCAT scores also were slightly lower that those of entering students in previous years.

An area of debate is whether critical thinking can be developed in college students or their maximum native ability is essentially set by the time of admission. Educational psychologists describe cognitive growth as a gradual and cumulative process. Thus, it may be unrealistic to expect large gains over the course of the program.[1] Furthermore, it is very difficult to "tease out the effect" of any particular course or educational strategy. If, due to rigorous selection criteria, pharmacy students generally have above-average thinking skills at the time of admission, causing a further increase may be difficult. However, not only does Perry's theory of intellectual development assume that critical thinking can be developed, research over many years has supported that gains can occur during college.[1,5,9,15,16] Most of these data come from nursing programs.

The most extensive longitudinal analysis of critical thinking skills to date was done by Peter and Noreen Facione with 7926 students in 145 samples from 50 predominately undergraduate nursing education programs around the United States.[9] The Facione study found an average CCTST score of 15.70 among nursing sophomores (who generally are in their first year of a professional program), 16.11 in juniors, and 16.40 in nursing seniors. For a subset of 625 students with matched admission and graduation scores, the mean admission CCTST score was 16.57 and the mean graduation score was 17.25 ($P < 0.001$). Thus, by either analysis, the increases in scores among nursing students were much smaller than those for our pharmacy classes, even though the higher admission scores of pharmacy students may have limited their ability to improve.

Another issue is whether the gains in CT ability are broad or are concentrated in specific subscales. In the nursing cohort, improvements were also most pronounced in the evaluation and induction subscales. This implies that health professions programs in general put emphasis on ability to evaluate the relative strength of information and to draw probabilistic inferences—a conclusion that seems quite reasonable.

It would be interesting to know whether some students are more prone to improve critical thinking than others. Ideally, those incapable of improved thinking skills could be kept out of the professional curriculum, while those who start low but are capable of increased ability could receive special attention. The Facione nursing study found that older age, sex, and prior work experience as a nurse did not predict improvement in CT skills at graduation. However, there was a good relationship between CCTST and the Academic College Testing (ACT) program scores, Scholastic Aptitude Test (SAT) scores, and Graduate Record Examination (GRE) scores.[9] They found no increase in scores for nonnative English speakers.[5] These data are consistent with other research demonstrating a significant relationship between verbal skills and higher order thinking ability.[5,9]

Some investigators have found that achieving a prior baccalaureate degree is a positive predictor of GPA and performance in pharmacy school,[17] but there was no evidence for this in the current study. Facione found that mere accumulation of college credits is not a predictor of CCTST score.[5] Some authors feel that men may be better critical thinkers than women because men are more detached and objective in thinking. Women tend to look for connections and emotional attachment to issues, and are less inclined to argue.[16] There was no difference between men and women in this sample, although pharmacy students are a highly select population. There was a good correlation between PCAT scores and CCTST scores, which suggests the PCAT strongly measures critical thinking ability.

In the Facione nursing cohort there were weak but statistically significant correlations (correlation coefficients of 0.235 to 0.341) between CCTST scores and nurses' grade point averages.[9] The current study found a similar correlation between admission GPA and CT score, but did not find a relationship between pharmacy program GPA and CT score. The lack of statistical relationship in this cohort may be partly due to the limited range in grade point average or a smaller study sample, or it may mean that most tests in our courses did not call upon the use of critical thinking skills.

Disposition toward critical thinking is also very important, but often overlooked. Mere increase in ability may be of no practical value if a pharmacist is not willing or able to use their skill without specific prompting or in novel situations. Knowing what is logical does not mean a pharmacist will do what is logical. In fact, a person who scores high on critical thinking confidence, but low on truth seeking and open mindedness could actually be quite dangerous. Facione found a statistically significant relationship between critical thinking disposition and CT ability ($r = 0.201$, $P < 0.001$ at entry to nursing programs and $r = 0.169$, $P < 0.001$ at graduation). This study found no correlation between disposition and ability (Table 4), although there was a correlation between disposition and *increase* in CT ability.

Once again, the data in this study, both for total scores and subscales, are very similar to what has been found in nursing students. Nursing students also scored below 40 on truth seeking and above 40 on other scales, and inquisitiveness was their strongest disposition. This profile would suggest that professional students tend to be passively open minded about others opinions, but not inclined to test the validity of their own opinions against the evidence.[9]

A valid question about the CCTST is whether it is based on scenarios that are similar to situations students will actually encounter in real life. The CCTST requires no discipline-specific knowledge, but is set in contexts familiar to college-aged students or older; it does not specifically assess application of skills in pharmacy contexts. There is some research that general critical thinking skills can be transferred to new situations.[1] However, Adamcik, et al could not find a correlation between Watson-Glaser CT scores and pharmacy-specific problem-solving exercises.[11]

In the 1970s medical educators thought that clinical reasoning was distinguished by the presence of generic problem-solving skills. If this were true, then development of critical thinking for its own sake would transfer to improved problem-solving ability in a pharmacy context. However, research revealed that expertise lay predominately in the knowledge that experts bring to a problem, and in particular, how experts structure that knowledge.[18] When people become better thinkers about a topic, their internal representations of the topic-related knowledge will become similar to the representations, called schemata, of experts in the field.[18] General problem-solving processes are only used for problems in unfamiliar domains.

Some authors believe critical thinking is quite independent of content.[19] If true, critical thinking ability by itself will be a determinant of success in a pharmacy curriculum only to the extent that instructors' assessments require critical thinking versus recall of content.

We can get students to mature in their thinking by introducing deliberate cognitive conflict. That is, we must purposely give opportunities for debate, asking questions, and reaching independent conclusions.[20] We must model open-mindedness and humility and encourage thoughtful analysis. Most importantly, we should give grades based on reasoning, logic, and alternative interpretations, otherwise students will quickly care only about the "right" answer. In addition, greater student participation in class and greater peer interaction is helpful. In other words, we need to create an environment that is interactive, challenging, and supportive of others' opinions.[16]

Why did our students increase in CT ability? Development of critical thinking is not covered in a discrete course in the curriculum, although it is an area of emphasis in the author's Drug Literature Evaluation course. The gradual increase seen is consistent with a general curricular effect. Facione found that higher CCTST scores in nursing curricula were correlated with adopting a CT focus for the whole curriculum, faculty discussions about the meaning of CT, and requiring a specific CT course in the curriculum.[9]

The increase in CCTST scores is probably not due to a testing effect from repeated exposure to the same test. Both the CCTST validation studies and the experiences of our students indicate that the questions do become familiar over time; however the complexity of reasoning required makes it difficult to be sure how one answered the question previously. More importantly, even if one remembers a previous answer, the student never knows the correct answer, and so the student must reason out the question each time if they wish to score well on the test. The authors of the CCTST have repeatedly found no evidence of a testing effect,[5] and this was ruled out in the present study by giving half of all graduating students an alternate (form B) version of the

CCTST. Students' scores on form A and form B did not differ.

An important limitation of this study is the lack of a comparison group in a nonpharmacy curriculum. Without a comparison group it is impossible to separate gains from maturation or the college experience in general from gains directly related to the pharmacy curriculum. In addition, results cannot be generalized beyond this one College of Pharmacy's unique curriculum. Another limitation is that the performance of multiple statistical tests on the data inflate the risk of type I statistical error.

Another problem is the scores on the CCTST could easily be affected by student motivation to do well. At first test administration, students were probably motivated to get off to a good start and give a strong effort. At subsequent administrations, as pressures of class work and other tests mounted, and the novelty of the test wore off, it is likely that some students did not give a full effort. Therefore, it is perhaps even more surprising that such positive results were noted. Another issue with this study design is the repeated testing. Theoretically, students could have become either test weary and reduced their effort, or test wise and improved their scores without a real increase in ability. Both phenomena may have occurred simultaneously, but are impossible to quantify. The investigator tried to minimize variations in effort from test weariness by always giving the test at an unexpected time during a normal class period.

CONCLUSION

Students in this curriculum increased in their critical thinking skills. We do not know what components of this curriculum, if any, led to the increases. Similarly, we need to know more about student characteristics, such as learning styles that contribute to critical thinking. It would also be useful to know if the observed gains will last. Will these students retain their ability 5 or 10 years from now? Many additional research questions can be asked. However, before effort can be made to study individual components of instruction, it is important to establish that gains are indeed possible. This study is a start in that direction. When research from other institutions, using different methods, is added to these data, a more complete picture should emerge.

REFERENCES

1. Halpern DF. Assessing the effectiveness of critical-thinking instruction. *J Gen Educ*. 1993; 42:239-254.

2. American Association of Colleges of Pharmacy Center for Advancement of Pharmaceutical Education. Educational Outcomes, 1998 Available at: http://www.aacp.org/Docs/MainNavigation/Resources/3933_edoutcom.doc?DocTypeID=4&TrackID=&VID=1&CID=525&DID=397. Accessed on November 18, 2003.

3. Daly J and Timmerman S. Critical thinking and problem solving. *J Am Pharm Assoc*. 1996; NS36 (October supplement);s1-s15.

4. Ennis RH. *Critical Thinking*. Upper Saddle River, NJ: Prentice-Hall;1996.

5. Facione PA, and Facione NC. *The California Critical Thinking Skills Test Manual*. California Academic Press, Millbrae, CA, 1998.

6. Hare W. Bertrand Russell on critical thinking. *J Thought*. 2001;36:7-16.

7. Perry WG. *Forms of Intellectual and Ethical Development in the College Years*. New York: Henry Holt; 1970.

8. Watson G and Glaser EM. *Watson-Glaser Critical Thinking Appraisal Manual*. San Antonio, TX: The Psychological Corporation; 1980.

9. Facione NC. *Critical Thinking Assessment in Nursing Education Programs: An Aggregate Data Analysis*. Millbrae, CA: California Academic Press; 1997.

10. Facione PA, Facione NC. Sanchez, C.A. *The California Critical Thinking Disposition Inventory Test Manual*. Millbrae, CA: California Academic Press; 1994.

11. Adamcik B., Hurley S, Erramouspe J. Assessment of pharmacy students' critical thinking and problem-solving abilities. *Am J Pharm Educ*. 1996;60:256-265.

12. Odedina F, Dukes N, Clemmons C, Relationship between critical thinking and pharmacy students' academic performance. *Am J Pharm Educ*. 2001;65:107s (abstract).

13. Allen DD, Bond CA. Prepharmacy predictors of success in pharmacy school: Grade point averages, pharmacy college admission test, communication abilities, and critical thinking skills. *Pharmacother*. 2001;21:842-849.

14. Duncan-Hewitt WC. Designing admissions criteria: A framework. *Am J Pharm Educ*. 1996;60:109-121.

15. Miller MA. Outcomes evaluation: Measuring critical thinking. *J Adv Nurs*. 1992;17:1401-07.

16. Cross KP, Steadman MH. *Classroom Research; Implementing the Scholarship of Teaching*. San Francisco: Josey-Bass;1996:191-3.

17. Chisholm M. Students performance throughout the professional curriculum and the influence of achieving a prior degree. *Am J Pharm Educ*. 2001;65:350-4.

18. Winslade N, A system to assess the achievement of doctor of pharmacy students. *Am J Pharm Educ*. 2001;65:363-392.

19. Paul RW. *Critical Thinking: How to Prepare Students for a Rapidly Changing World*. Santa Rosa, CA: Foundation for Critical Thinking; 1995.

20. King A. Inquiring minds really do want to know: Using questioning to teach critical thinking. *Teach Psychol*. 1995;22:13-17.