UNIVERSITY OF HOUSTON
OFFICE OF INSTITUTIONAL EFFECTIVENESS

RECEIVED APR 11 2008

TO: UNDERGRADUATE COUNCIL
FROM: LIBBY BARLOW
SUBJECT: ASSESSMENT OF CRITICAL THINKING
DATE: 4/14/2008

On February 21, 2007, the Undergraduate Council approved recommendations from the Core Committee about general education assessment. Among the recommendations in the document is a proposal for Institutional Effectiveness to begin the process of evaluating critical thinking. This memorandum is a progress report on assessment of critical thinking as a core competency.

A faculty group was assembled to develop a rubric for measuring critical thinking among University of Houston undergraduate students according to expectations set by our faculty. Each college was invited to send a representative. Working group members are listed below:

Libby Barlow, Institutional Effectiveness
Simon Bott, Chemistry
Bill Dupre, Geosciences
Martha Haun, Communications
Cathy Horn, Educational Psychology
Phil Howard, History
Steve Liparulo, Writing Center
Bill Nelson, Philosophy
Charles Peters, Mathematics
George Trail, English
Len Trombetta, Electrical and Computer Engineering
Maria Elena Solino, Hispanic Studies
Lori Whisenant, Management

The group completed a pilot project designed to establish a measurement rubric and a viable plan for a full-scale assessment. The rubric, attached, was developed for UH using elements from the Washington State University Scoring Guide for Critical and Integrative Thinking and outcomes identified by the National Council for Excellence in Critical Thinking Instruction as a starting point. The resulting provisional rubric retains many of these elements, edited for UH priorities and multidisciplinary assessment.

The rubric was pilot-tested on samples archived in WebCT of Fall 2007 student work reflecting critical thinking. This avoided delaying the pilot assessment an entire semester while waiting for sufficient data from spring semester courses. With the assistance of Educational Technology staff and after notifying faculty with course material stored in WebCT, we identified 4000-level

courses where the course management system's assignment tool had been activated. The presence of the assignment tool served as an indicator that written work of some kind had been submitted. Instructors for those courses were then contacted to see if they could recommend written work from their courses that might be examined for evidence of students' critical thinking skills.

The rubric and scoring guide, appended, were devised through consideration of best practices and refined through several rounds of benchmark ratings; they articulate a working definition of critical thinking for UH. Significant discussion was devoted to the question of whether a single rubric can appropriately measure critical thinking across disciplines, including the sciences. The committee made little attempt to capture evidence of critical thinking within mathematics courses, at least in part because a parallel pilot for quantitative reasoning assessment is underway and may be a more appropriate measure of critical thinking in that discipline. Based only on the voluntary responses from instructors, papers were collected for critical thinking representing 8 subjects (BIO, DISC, ECE, TELS, POLS, PHAR, CUIN, GENB) and 7 colleges (CLASS, Business, Engineering, Education, Technology, Pharmacy, NSM). After examination of student work from these disciplines, including Engineering and Technology, committee members felt the rubric was successful, a sense that was validated by the consistency of the scoring results. The scoring effort did, however, reveal that not every piece of written work is appropriately scored against a critical thinking rubric. It is assumed that no assignment is designed specifically for students to demonstrate critical thinking alone, but that critical thinking is a background skill demonstrated in a broad range of assignments. However, some assignments may expect students to show just one isolated piece of the critical thinking process, so it was concluded we would be dependent on faculty to identify assignments that could reasonably be expected to display most of the critical thinking process.

The group determined that the next step in the assessment project is to distribute the rubric and scoring guide to the faculty. Broad distribution will provide an opportunity for faculty not engaged in the rubric development process to provide feedback and allow wider discussion of critical thinking before a full-scale assessment is undertaken. When there has been sufficient opportunity for feedback, faculty will be asked to identify written work in which we could expect to find evidence of critical thinking. Assignment information and associated student work will then be collected, using a process that will yield a sample as representative of the undergraduate population as can be achieved using this kind of embedded assessment. The rubric has several categories, each of which will yield a unique set of scores, thereby making it possible to isolate dimensions of critical thinking warranting further examination or reinforcement in the curriculum. It is important to emphasize that the object of interest is critical thinking skills among our students in general, and that results will speak to what our students know or are able to do. Any conclusions drawn from the results would most likely have implications for the core curriculum, but determination of specific actions would be in the hands of the faculty. To that end, scoring will be recorded and analyzed without identification of the student or the instructor.

Effective use of the rubric for scoring is best facilitated by training a group of raters who will engage in norming sessions and will be able see the scoring task through to completion. This could be accomplished by faculty or possibly by doctoral students. The end result of the scoring process may include further refinement of the rubric, which must always reflect UH faculty expectations for critical thinking. Final determination of scoring personnel will be accomplished in consultation with associate deans and department chairs before the end of the 2007-08 academic year. The precise timing of the full-scale assessment will be contingent upon this

decision, but collection of a complete set of data should extend no longer than the next long semester, Fall 2008.

The primary goal of this assessment is to provide undergraduate faculty with reliable information on the status of students' critical thinking skills. The assessment must measure critical thinking as defined by our faculty, and provide actionable results. Since critical thinking is neither taught nor demonstrated in one discipline to the exclusion of others, it is especially important that the assessment development process both solicit input from faculty across campus and communicate back to faculty how expectations for critical thinking as a core competency are defined at the University of Houston. The progress of this pilot assessment to date leaves us well positioned to move forward with a full-scale assessment.

Provisional University of Houston Critical Thinking Rubric 2008

Identifies problem, question, or issue (raises questions, formulated clearly and precisely)

Unacceptable	***Acceptable***	***Exemplary***
- Does not attempt to or fails to identify and summarize accurately.	- Summarizes issue, though some aspects are incorrect or confused. Nuances and key details are missing or glossed over.	- Clearly identifies the challenge and subsidiary, embedded, or implicit aspects of the issue.

Presents, interprets, and analyzes relevant information, data, or evidence (gathers relevant information, using disciplinary concepts to interpret it effectively)

- Little or no evidence of search, selection or source evaluation skills. - Repeats information provided without question or dismisses evidence without adequate justification. - Data/evidence or sources are simplistic, inappropriate, or not related to topic.	- Demonstrates adequate skill in searching, selecting, and evaluating sources to meet the information need. - Use of evidence is qualified and selective. - Discerns fact from opinion and may recognize bias in evidence, although attribution is inappropriate.	- Evidence of search, selection, and source evaluation skills. - Examines evidence and its source; questions its accuracy, relevance, and completeness.

Considers context, assumptions, and other perspectives (thinks open-mindedly, considering multiple sources and options, assessing the credibility and authority of sources)

- Approach to the issue is in egocentric or socio-centric terms. - Analysis is grounded in absolutes, with little acknowledgment of own biases. - Engages ideas that are obvious or agreeable. Avoids challenging or discomforting ideas.	- Provides some recognition of context and consideration of assumptions and their implications. - Engages challenging ideas tentatively or in ways that overstate the conflict. - May dismiss alternative views hastily.	- Analysis acknowledges complexity and bias of vantage and values, although may elect to hold to bias in context. - Identifies influence of context and questions assumptions, addressing ethical dimensions underlying the issue. - Integrates own and others' ideas in a complex process of judgment and justification. - Clearly justifies own view while respecting views of others.

Develops and presents argument, position or hypothesis, with implications		
Unacceptable	***Acceptable***	***Exemplary***
- Argument, position, or hypothesis is clearly inherited or adopted with little original consideration. - Fails to present and justify or forward argument, position, or hypothesis. - Argument, position, or hypothesis is unclear or simplistic.	- Argument, position, or hypothesis includes some original thinking that acknowledges, refutes, synthesizes or extends other assertions, although some aspects may have been adopted.	- Presents and justifies clearly and in sufficient detail own argument, position, or hypothesis while qualifying or integrating contrary views or interpretations.
Draws meaningful or justified conclusions (comes to well-reasoned conclusions and solutions, tested against relevant criteria and standards)		
- Fails to identify conclusions, implications, and consequences, or conclusion is a simplistic summary. - Conclusions presented as absolute, and may attribute conclusion to external authority.	- Conclusions consider or provide evidence of consequences extending beyond a single discipline or issue. Presents implications that may impact other people or issues. - Presents conclusions as relative and only loosely related to consequences. Implications may include vague reference to conclusions.	- Identifies, discusses, and extends conclusions, implications, and consequences. Considers context, assumptions, data, and evidence. Qualifies own assertions with balance. - Conclusions are qualified as the best available evidence within the context. - Consequences are considered and integrated. Implications are clearly developed, and consider ambiguities.
Communicates with regard to complex problems (adapts communication to target audience and disciplinary conventions)		
- Grammar, syntax, or other errors are distracting or repeated. Little evidence of proofreading. Style is inconsistent or inappropriate. - Work is unfocused and poorly organized; lacks logical connection of ideas. Format is absent, inconsistent or distracting. - Few sources are cited or used correctly.	- Errors are not distracting or frequent, although there may be some problems with more difficult aspects of style and voice. - Basic organization is apparent; transitions connect ideas, although they may be mechanical. Format is appropriate although at times inconsistent. - Most sources are cited and used correctly.	- Errors are minimal. Style is appropriate for audience. - Organization is clear; transitions between ideas enhance presentation. Few problems with format or other components of presentation. - All sources are cited and used correctly, demonstrating understanding of economic, legal and social issues involved with the use of information.

This rubric incorporates substantial portions of the Washington State University Scoring Guide for Critical and Integrative Thinking and outcomes identified for a well cultivated critical thinker by the National Council for Excellence in Critical Thinking Instruction.

UH Critical Thinking Assessment:
Provisional Scoring Guide 2008

The order in which the Criteria appear is not intended to suggest sequence.	not applicable	unacceptable	acceptable	exemplary
Criteria:	**NA**	**1**	**2**	**3**
Identifies **problem, question,** or **issue** (raises questions, formulated clearly and precisely)				
Presents, interprets, and analyzes relevant **information, data, or evidence** (gathers relevant information, using disciplinary concepts to interpret it effectively)				
Considers **context, assumptions,** and **other perspectives** (thinks open-mindedly, considering multiple sources and options, assessing the credibility and authority of sources)				
Develops and presents **argument, position, or hypothesis**, with implications				
Draws meaningful or justified **conclusions** (comes to well-reasoned solutions, tested against relevant criteria and standards)				
Communicates with regard to complex problems (adapts communication to target audience and disciplinary conventions)				

This rubric incorporates substantial portions of the Washington State University Scoring Guide for Critical and Integrative Thinking and outcomes identified for a well cultivated critical thinker by the National Council for Excellence in Critical Thinking Instruction.

Appendix A
Free Response Items by Performance Levels

Math1310 ,Test 2, Question 14	Number	Percent	Cumulative Percent
Exemplary	45	54%	54%
Acceptable	11	13%	67%
Basic	15	18%	85%
Not Acceptable	13	15%	100%
Total	84	100%	

Math1310 ,Test 2, Question 15	Number	Percent	Cumulative Percent
Exemplary	64	76%	76%
Acceptable	4	5%	81%
Basic	4	5%	86%
Not Acceptable	12	14%	100%
Total	84	100%	

Math1310 ,Test 4, Question 10	Number	Percent	Cumulative Percent
Exemplary	23	30%	30%
Acceptable	16	21%	51%
Basic	22	29%	79%
Not Acceptable	16	21%	100%

Total	77	100%	

Math1310 ,Test 4, Question 11	Number	Percent	Cumulative Percent
Exemplary	12	16%	16%
Acceptable	13	17%	32%
Basic	25	32%	65%
Not Acceptable	27	35%	100%
Total	77	100%	

Math1313 ,Test 2, Question 13	Number	Percent	Cumulative Percent
Exemplary	41	51%	51%
Acceptable	14	17%	68%
Basic	11	14%	81%
Not Acceptable	15	19%	100%
Total	81	100%	

Math1314 ,Test 3, Question 9	Number	Percent	Cumulative Percent
Exemplary	10	14%	14%
Acceptable	40	55%	68%
Basic	7	10%	78%
Not Acceptable	16	22%	100%
Total	73	100%	

Math1330 ,Test 2, Question 16	Number	Percent	Cumulative Percent
Exemplary	11	14%	14%
Acceptable	16	21%	35%
Basic	2	3%	37%
Not Acceptable	49	63%	100%
Total	78	100%	

Math1330 ,Test 4, Question 13	Number	Percent	Cumulative Percent
Exemplary	0	0%	0%
Acceptable	15	24%	24%
Basic	15	24%	48%
Not Acceptable	33	52%	100%
Total	63	100%	

Math1330 ,Test 3, Question 14	Number	Percent	Cumulative Percent
Exemplary	35	49%	49%
Acceptable	2	3%	52%
Basic	10	14%	66%
Not Acceptable	24	34%	100%
Total	71	100%	

General Education Assessment of Quantitative Reasoning at the University of Houston

Introduction

Quantitative reasoning is an integral part of the core curriculum at the University of Houston and a key focus of the general education assessment effort. By choosing to add this institutionally designated option to the state mandated core curriculum, the university recognizes the importance of student learning in this area.

Quantitative reasoning is a multi-faceted construct which is owned by several disciplines housed on our university campus. While an assessment framework that encompasses more than one discipline is warranted, a decision was made to implement a pilot study of quantitative reasoning in one discipline to test an assessment protocol and to determine the feasibility of implementing this protocol on a larger scale. At the University of Houston, mathematics lends itself well to such a project in part because math reasoning is a good proxy for quantitative reasoning but also because math tends to have well-defined learning objectives and student performance data.

In mathematics, quantitative reasoning is entwined with student competencies. If one were to consider Bloom's taxonomy, students must acquire knowledge before they can *apply* knowledge. Similarly, reasoning in mathematics is possible only after students have attained pre-reasoning skills, which include axiomatic knowledge (i.e., math rules). Therefore, the pilot study examined student outcomes with respect to not only reasoning skills but also the foundational learning that enables reasoning as defined by the math curriculum.

The assessment strategy for math competencies at the University of Houston reflects four general learning objectives adopted from the core curriculum guidelines established by the Texas Higher Education Coordinating Board (THECB) (Texas Higher Education Coordinating Board, 2008). Stated in terms of what students are expected to do, these objectives are:

- To apply arithmetic, algebraic, geometric, higher-order thinking, and statistical methods to modeling and solving real world problems
- To represent and evaluate basic mathematical information verbally, numerically, graphically, and symbolically

- To expand mathematical reasoning skills and formal logic to develop convincing mathematical arguments.

- To interpret mathematical models such as formulas, graphs, tables and schematics, and draw inferences from them

These learning objectives are consistent with the University of Houston core curriculum reasoning requirement that includes "building students' skills in mathematical and logical thinking" (University of Houston, 2008).

In order to assess student progress, the four learning objectives were mapped to four lower division courses.

- MATH 1310: College Algebra
- MATH 1313: Finite Mathematics with Applications
- MATH 1314: Calculus for Business and the Life Sciences
- MATH 1330: Pre-calculus

The rationale for choosing these particular courses is that a high proportion of undergraduates enroll in these classes as part of their degree plan. Thus, these courses provide the most appropriate data from which to study the acquisition of quantitative reasoning skills. (The reader is reminded that the quantitative reasoning construct is operationalized for the purposes of this pilot to be student work that reflects mathematical reasoning.)

Assessment Structure and Definitions

In order to assess the extent of student learning in math, the Mathematics Department collaborated with the University of Houston - Office of Institutional Effectiveness to identify specific courses and data items appropriate for the task. These courses and items represent an initial "pilot" framework that will guide the long term assessment strategy in this area.

I. Learning Objectives and Assessment Items

Table 1 maps specific exam items in four undergraduate math courses against the general education objectives for math competency. The selected items were reviewed by the math department – in collaboration with institutional research and assessment personnel – for their relevance and appropriateness to the specified learning objectives. It is important to note that a single test item may address more than one objective. For example, in the Table 1 the column

for MATH 1330 contains two references to Item 4 from Test 2, addressing Objective 2 and Objective 4.

Table 1: Assessment Items by Course and Learning Objective*

Learning Objectives	Course			
	MATH 1310	MATH 1313	MATH 1314	MATH 1330
Objective 1: To apply arithmetic, algebraic, geometric, higher-order thinking, and statistical methods to modeling and solving real world problems	Test 2: **15**, **14**	Test 2: 6 Test 3: 2	Test 2: 2 Test 3: 4, **9** Test 4: 1, 7, 8	Test 3: 3 Test 4: 2, 9
Objective 2: To represent and evaluate basic mathematical information verbally, numerically, graphically, and symbolically	Test 4: 9, **10**, **11**	Test 2: **13** Test 3: 1, 3	Test 3: 5 Test 4: 2	Test 2: 4, 10 Test 4: **13**
Objective 3: To expand mathematical reasoning skills and formal logic to develop convincing mathematical arguments	Test 3: 6 Final: 3		Test 3: **9**	Test 3: **14** Test 4: 5, 6, **13**
Objective 4: To interpret mathematical models such as formulas, graphs, tables and schematics, and draw inferences for them	Test 3: 8 Test 4: 7	Test 2: 5, **13** Test 3: 5, 12	Test 3: 3, **9**	Test 2: 4, **16** Test 3: 12 Test 4: 5, 6

* Bold items represent free response questions

II. Item Type and Performance Levels

Exams represent the majority of assessments utilized by instructors in lower division mathematics courses. Therefore, the assessment strategy described here utilizes two types of data items: multiple choice (MC) and free response.

Item Difficulty

Math instructors and assessment staff routinely review the exams to evaluate the quality of the questions. Instructors also jointly determine item difficulty, which is rated on a three point scale of A, B, & C where "A" is most

difficult and "C" is least difficult. In practical terms, an "A" level item requires "A" level understanding and skill, and a student earning an "A" in the class would be expected to answer the question correctly. A "B" level item requires "B" level comprehension and so on. Exams are constructed to have a mixture of A, B and C level questions so as to delineate differing levels of student understanding of concepts. As a result, interpretation of aggregate student performance on a given item must take item difficulty into account since the percentage of students answering a question correctly will likely vary depending on the difficulty of the questions. The item difficulty level is incorporated into the performance standards as illustrated in the following sections.

Performance Standards

The performance standards for the mathematics exams are derived from patterns of student outcomes in these courses from the past year. In short, the expected performance benchmark for A, B and C level questions was set by the average percent of students receiving A's, B's and C's in the respective math courses during the previous year. **Table 2** provides the benchmarks for student performance relative to test item difficulty.

Table 2: Minimum Performance Benchmarks by Course and Item Difficulty

	Courses			
Item Difficulty Level	Math 1310	Math 1313	Math 1314	Math 1330
A Level	22%	22%	21%	16%
B Level	44%	42%	44%	34%
C Level	60%	60%	59%	52%

In terms of multiple choice items, the figures above represent the minimum acceptable percentage correct for a given item difficulty. For example, if 61% of students in Math 1310 answer a "C" level item correctly, they will have met the standard of performance for that item.

The rationale for free response items is similar. In this case, the percentages from Table 2 indicate the minimum group performance expectation for each free response item defined as the proportion of responses that are "acceptable" or better. For instance, 42% of students in Math 1313 would be expected to provide an "acceptable" or "exemplary" answer to a "B" level free response item. In Math 1330, the group performance expectation would be 34% for the same item

Performance Levels for Multiple Choice Items

Performance standards for each type of item are slightly different and bear additional discussion. Standards for multiple choice items are applied to aggregate student results. Put simply, did students as a group do well enough on an item to demonstrate adequate learning at the program level? As mentioned previously, the performance standards are divided into three tiers to account for item difficulty. If an item represents "A" level content, then the percentage of students expected to answer that item correctly would be lower relative to the expectation for a "C" level question.

Performance Levels for Free Response Items

While multiple choice items primarily result in binary outcomes (correct vs. incorrect), free responses require a more complex grading system. Each free response item is composed of multiple parts and points are awarded cumulatively. In other words, success on later components of the problem is dependent on how well students perform on earlier stages. The more a student knows and understands the course material, the higher the likelihood of the student answering a given item accurately and completely. Points are assigned accordingly. Since the total point values for each question different slightly depending on the number of item components, the math department has set specific performance cut points for each item. Regardless of the total number of points, performance on each item is expressed in terms of four performance levels. These are:

Needs Improvement: Student is lacking the prerequisite skills necessary to take the first step towards solving the problem.

Basic: Student has demonstrated that he/she has the pre-requisite skills to set up the problem and/or take the first step towards solving the problem.

Acceptable: Student has demonstrated sufficient knowledge to solve the problem.

Exemplary: Student has completed every step required to solve the problem correctly and has reported the answer correctly.

Although there are four possible student performance levels, the critical cut score is the point at which students are classified as "acceptable" since this represents the minimum math target outcome for these items. It is reasonable to assume that difficult items will have fewer students attaining acceptable status compared to less difficult items. Therefore, different cut points are set based on the three item difficulty levels (e.g. A, B, and C). The actual performance standards (i.e. minimum percentage needed for each performance level) are based on student outcome patterns in previous courses.

Results

The results of the item analysis are organized by learning objective. This allows us to address individual objectives in terms of student performance on the appropriate items relative to the standards. The columns titled "% Correct" and "% Acceptable or higher" provide the actual student assessment results while a check in the "Met Standard" column indicates whether the overall aggregate results meet the threshold of acceptable performance as described in the previous section when factoring in item difficulty. Please note that item difficulty is indicated by a letter after each item in the tables (e.g. Test 2:15 (B)).

Objective 1: To apply arithmetic, algebraic, geometric, higher-order thinking, and statistical methods to modeling and solving real world problems

Course	MC Items	% Correct	Met Standard	Free Response Items	% Acceptable or higher	Met Standard
MATH 1310				Test 2: 15 (B)	81%	✓
				Test 2: 14 (A)	67%	✓
MATH 1313	Test 2: 6 (C)	93%	✓			
	Test 3: 2 (C)	49%	-			
MATH 1314	Test 2: 2 (B)	52%	✓			
	Test 3: 4 (C)	95%	✓			
	Test 4: 1 (B)	85%	✓	Test 3: 9 (A)	68%	✓
	Test 4: 7 (A)	60%	✓			
	Test 4: 8 (B)	62%	✓			
MATH 1330	Test 3: 3 (C)	65%	✓			
	Test 4: 2 (C)	43%	-			
	Test 4: 9 (A)	49%	✓			

Objective 2: To represent and evaluate basic mathematical information verbally, numerically, graphically, and symbolically

Course	MC Items	% Correct	Met Standard	Free Response Items	% Acceptable or higher	Met Standard
MATH 1310	Test 4: 9 (A)	66%	✓	Test 4: 10 (B)	51%	✓
				Test 4: 11 (B)	32%	-
MATH 1313	Test 3: 1 (C)	81%	✓	Test 2: 13 (B)	68%	✓
	Test 3: 3 (C)	74%	✓			
MATH 1314	Test 3: 5 (B)	46%	✓			
	Test 4: 2 (A)	96%	✓			
MATH 1330	Test 2: 4 (B)	56%	✓	Test 4: 13 (A)	24%	✓
	Test 2: 10 (A)	45%	✓			

Objective 3: To expand mathematical reasoning skills and formal logic to develop convincing mathematical arguments.

Course	MC Items	% Correct	Met Standard	Free Response Items	% Acceptable or higher	Met Standard
MATH 1310	Test 3: 6 (C)	81%	✓			
	Final: 3 (C)	93%				
MATH 1314				Test 3: 9 (A)	68%	✓
MATH 1330	Test 4: 5 (A)	54%	✓	Test 3: 14 (A)	52%	✓
	Test 4: 6 (A)	54%	✓	Test 4: 13 (A)	24%	✓

Objective 4: To interpret mathematical models such as formulas, graphs, tables and schematics, and draw inferences for them

Course	MC Items	% Correct	Met Standard	Free Response Items	% Acceptable or higher	Met Standard
MATH 1310	Test 3: 8 (B)	71%	✓			
	Test 4: 7 (C)	74%	✓			
MATH 1313	Test 2: 5 (C)	79%	✓	Test 2: 13 (B)	68%	✓
	Test 3: 5 (C)	87%	✓			
	Test 3: 12 (A)	39%	✓			
MATH 1314	Test 3: 3 (B)	46%	✓	Test 3: 9 (A)	68%	✓
MATH 1330	Test 2: 4 (B)	56%	✓	Test 2: 16 (B)	35%	✓
	Test 3: 12 (A)	78%	✓			
	Test 4: 5 (A)	54%	✓			
	Test 4: 6 (A)	54%	✓			

In sum, results indicate that students are meeting the general education benchmarks for acceptable performance in mathematics. Outcome data for each objective suggest that students are able to demonstrate learning at a level consistent with the goals of the math program. The range of item difficulty provides additional insight regarding the depth of knowledge acquired by students across the available courses.

Discussion

The assessment process described in this report represents the first phase of a multi-year strategy to refine how the university evaluates student progress in quantitative reasoning skill acquisition. The results of this study will lead to a two-pronged assessment strategy. First, there will becontinued development and refinement of the general math component of core curriculum assessment. Secondly, the university will expand the scope of quantitative reasoning assessment to include the other university disciplines that own the responsibility for teaching these skills. Each of these projects will be discussed in turn.

General Math Assessment – Next Steps

Mathematics faculty will undertake a review of these objectives to determine whether these should be revised to better address our students' needs. The first stage of the review (FY 2008/2009) will utilize instructors from the four courses described in this report. However, the math department will continue to map exam items to the appropriate objectives for evaluative purposes only making changes when appropriate and consistent with the overall assessment approach.

In FY 2009-10, the scope of assessment will be expanded to incorporate additional courses. This will provide a wider net for gauging general student learning in math. It is likely that the first course to be added to this process is MATH 2311: Introduction to Probability and Statistics. The class provides foundational knowledge in an area of mathematics that permeates everyday life and is in keeping with mission of the university to create quantitatively literate graduates.

Quantitative Reasoning – Next Steps

Within the framework of the university curriculum, mathematics and quantitative reasoning represent parallel learning paths. As discussed previously, quantitative reasoning is not owned by a single discipline. Quantitative reasoning skills may be learned in fields such as philosophy, computer science, and music. This pilot study provides a springboard for interdisciplinary discussions with respect to quantitative reasoning at the University of Houston. The ultimate goal is to develop a general education assessment protocol that incorporates the relevant skills and knowledge from each of these disciplines into a comprehensive continuous improvement plan.

References

Texas Higher Education Coordinating Board (2008). Core curriculum: assumptions and defining characteristics. THECB Website. Retrieved March 25, 2007 from http://www.thecb.state.tx.us/AAR/UndergraduateEd/fos_assumpdef.cfm

University of Houston (2008). Degree requirements: core curriculum requirements. The University of Houston Website. Retrieved March 25, 2007 from http://www.uh.edu/academics/catalog/general/acade3.html#core_req

Appendix B

Math 1310, Test 2 Problem 14 Objective 1

Solve the system of equations by elimination or substitution

$2x + 4y = 1$
$x + 4y = 3$

Free Response: 10 points

Points break down:

Problem set-up	4 – 7 points
y = a fraction	7 – 8 points
x = – fraction	9 – 10 points

Item difficulty: A

Math 1310, Test 2, Problem 15 Objective 1

A piggy bank contains an equal number of pennies, nickels, dimes and quarters. If the total amount of money in the bank is $5.33, find the number of each kind of coin.

Free Response: 10 points

Points break down:

Equation	5 points	basic
Arithmetic	2 points	competent
Answer	3 points	exemplary

Item difficulty: B

Math 1310, Test 3, Question 6 Objective 3

Which of the following functions matches the graph below?

A) $f(x)=(x-2)^3-1$

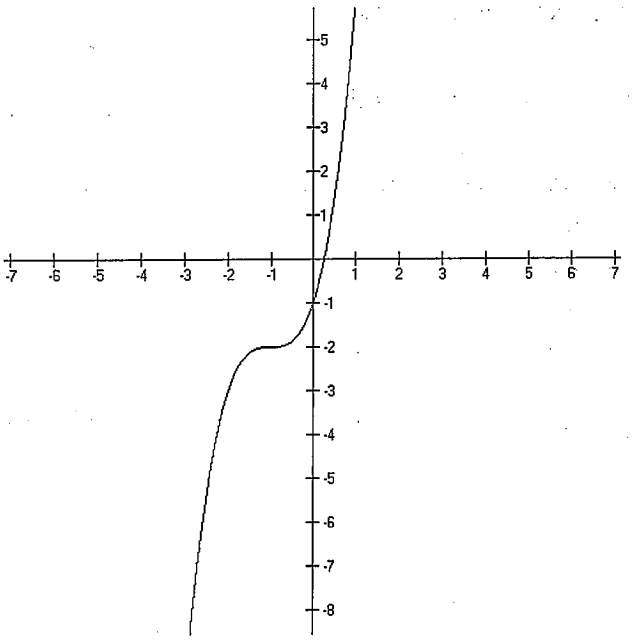
B) $f(x)=-(x+1)^3-2$

*C) $f(x)=(x+1)^3-2$

D) $f(x)=(x-1)^3-2$

E) $f(x)=(x+2)^3+1$

F) none of the above



Item difficulty: C

Math 1310, Test 3, Problem 8 Objective 5

Find the maximum or minimum value of the function:

$$f(x) = x^2 + 16x + 68.$$

A) The minimum value is 8.
*B) The minimum value is 4.
C) The minimum value is −4.
D) The maximum value is −4.
E) The maximum value is 4.
F) None of the above.

Item Difficulty: B

Math 1310, Test 4, Problem 7 Objective 4

Let $f(x)=\frac{2(x+9)^2}{x^2-81}$.

Find any holes.

A) The function does not have any holes.
B) There is a hole at $x = 1$.
C) There is a hole at $x = 9$.
*D) There is a hole at $x = -9$.
E) There is a hole at $x = -1$.
F) None of the above.

Item Difficulty: C

Math 1310, Test 4, Problem 9 Objective 2

Find a polynomial with integer coefficients that satisfies the following conditions:

Degree of polynomial:	3
Zeros:	1, −2i, 2i
Constant coefficient:	−12

A) $x^3 - x^2 + 4x - 12$

B) $3x^3 - 3x^2 - 12x - 12$

C) $3x^3 + 3x^2 + 3x + 12$

D) $-x^3 - x^2 + 12x - 12$

*E) $3x^3 - 3x^2 + 12x - 12$

F) None of the above.

Item Difficulty: A

Math 1310, Test 4, Problem 10 Objective 2

Graph: $P(x) = x(x+1)^2(x-9)^3$.

On your graph clearly label the x-intercept(s), and y-intercept. Show the correct end behavior and the correct behavior at each x-intecept.

9 points

Point break down:

Labeling the 3 intcepts:	3 points
Correct behavior at Intercepts	2 points 4 points

Item Difficulty: B

Math 1310, Test 4, Problem 11 Objective 2

Graph: $f(x)=\frac{x-3}{x+6}$

State the following and clearly label on your graph:

a) x-intercept(s)
b) hole(s)
c) y-intercept(s)
d) vertical asymptote(s)
e) horizontal asymptote(s)

10 points

Points break down

Intercepts	4 points	basic
Asymptotes	4 points	competent
Graph	2 points	exemplary

Item Difficulty: B

Math 1310, Final, Problem 3 Objective 3

Solve the equation

$$\frac{12}{x}=\frac{6}{5}$$

A. 9
B. 11
C. 4
D. 10
E. 6
F. none of the above

Item difficulty: C

Math 1313, Test 2, Problem 5 Objective 4

Given that the augmented matrix in row-reduced form is equivalent to the augmented matrix of a system of linear equations. Determine whether the system had a solution and find the solution(s) to the system, if they exist.

$$\left(\begin{array}{ccc|c} 1 & 0 & 0 & a \\ 0 & 1 & 0 & b \\ 0 & 0 & 1 & c \end{array}\right)$$

A) No solution.
*B) $x = a, y = b, z = c$
C) $x = a, y = b$
D) $x = -a, y = -b, z = -c$
E) $x = -a, y = -b$
F) None of the above.

Item difficulty: C

Math 1313, Test 2, Problem 6 Objective 1

Given $A = \begin{pmatrix} a & b & c \\ d & e & f \\ g & h & i \\ j & k & l \\ m & n & p \end{pmatrix}$ Find it's transpose.

A) transpose A

B) $\begin{pmatrix} c & b & a \\ f & e & d \\ i & h & g \\ l & k & j \\ p & n & m \end{pmatrix}$

C) $\begin{pmatrix} c & f & i & l & p \\ b & e & h & k & n \\ a & d & g & j & m \end{pmatrix}$

D) – transpose A

E) $\begin{pmatrix} -c & -f & -i & -l & -p \\ -b & -e & -h & -k & -n \\ -a & -d & -g & -j & -m \end{pmatrix}$

F) None of the above

Item difficulty: C

Math 1313, Test 2, Question 13 Objectives 2 and 4

Given the following system of equations, solve using the Gauss-Jordan Elimination Process.

$$x-2y+2z=8$$
$$y-z=-4$$
$$4y-6z=-18$$

The augmented matrix is:

$$\left[\begin{array}{ccc|c} 1 & -2 & 2 & 8 \\ 0 & 1 & -1 & -4 \\ 0 & 4 & -6 & -18 \end{array}\right]$$

(Note: The dotted vertical line in the matrix above should be a single vertical line.)

Item difficulty: B

Math 1313, Test 3, Problem 1 Objective 2

A problem is listed below. Identify it's type.

Right Wash is a washateria that has realized they will need to replace 4 dryers in 1 year. They deposite $6400 in an account that earns 1.8% per year compounded quarterly. How much will they have toward the purchase of the dryers at the end of 1 year?

A) Sinking fund
B) Present value with compound interest
C) Future value of an annuity
D) Present value of an annuity
E) Future value with compound interest
F) None of the above.

Item difficulty: C

Math 1313, Test 3, Problem 2 Objective 1

A library decides to buy a new computers system though Tech Company. They make a down payment of $2600. If Tech Company charges 7% per year compounded quarterly for 3 years, and the library's quarterly payment are $14,000, what is the purchase price of the computer system?

A) $155553.70
B) $150385.70
C) $152953.70
D) $182551,45
E) $187751.45

Item difficulty: C

Math 1313, Test 3, Problem 3 Objective 3

A problem is listed below. Identify its type.

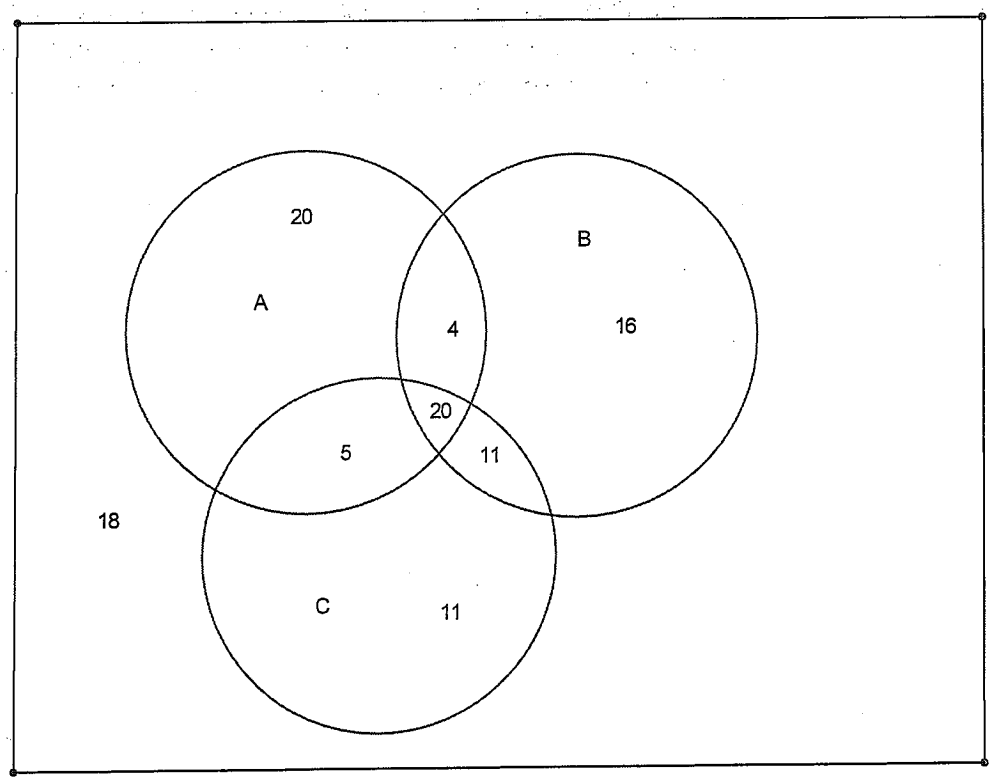
A newly formed band would like to buy all new instruments from Sounds, Inc. In order to have a down payment for the instruments, the band decides to deposit $600 each quarter in an account that earns 3.89% per year compounded quarterly for 3 years. How much will the band have for a down payment on the instruments in 3 years?

A) Present value of an annuity
B) Present value with compound interest
C) Sinking Fund
D) Future value of an annuity
E) Amortization
F) None of the above.

Item difficulty: C

Math 1313, Test 3, Problem 5 Objective 5

Given the following Venn diagram, find $n[(A \cup B)^c \cap C]$.

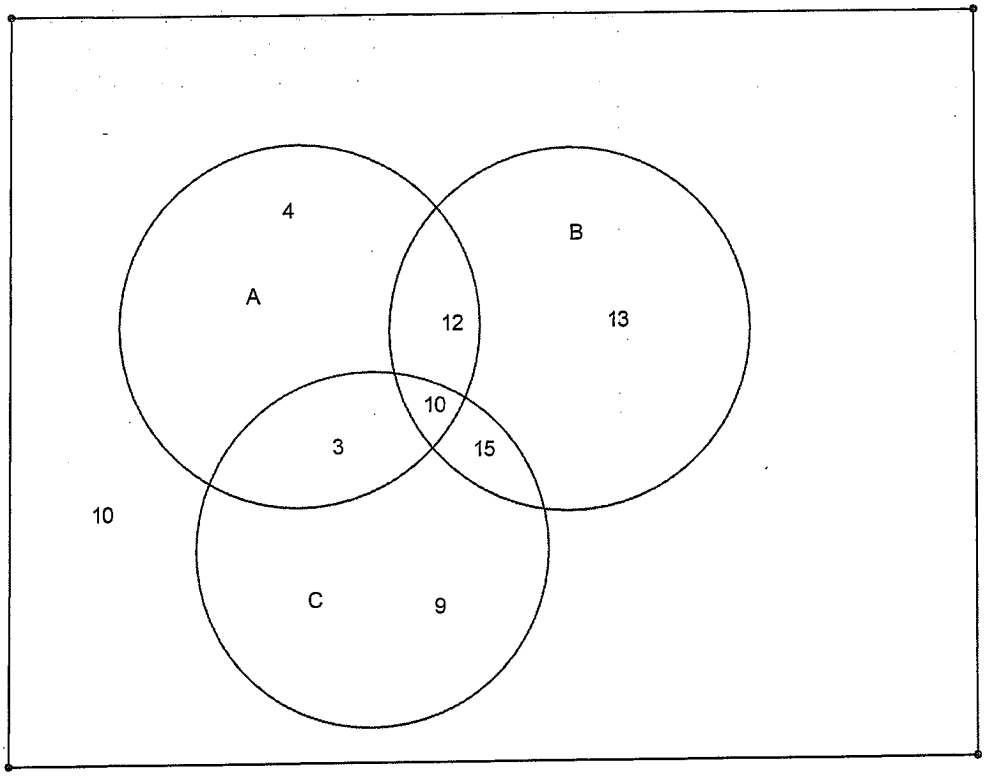


A) 37
B) 38
C) 33
D) 11
E) 35
F) None of the above.

Item difficulty: C

Math 1313, Test 3, Problem 12 Objective 5

Given the following Venn Diagram, find $n(B^c \cup C)$.



A) 26
B) 12
C) 9
D) 51
E) 41
F) None of the above.

Item difficulty: A

Math 1314, Test 2, Problem 2 Objective 1

Compute: $\lim_{x \to 5} \left(\frac{x^2 - 15x + 50}{x - 5} \right)$

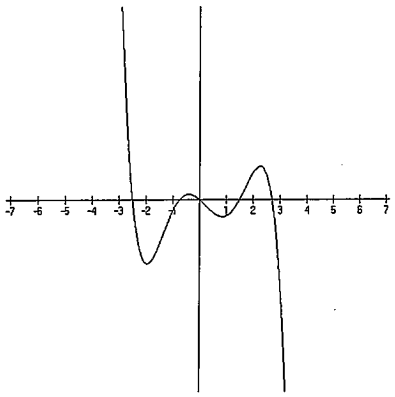
A) –25
B) 0
C) 15
D) –5
E) The limit does not exist.
F) None of the above.

Item Difficulty: B

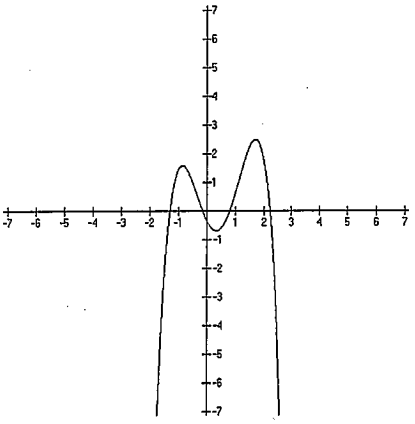
Math 1314, Test 3, Problem 3 Objective 4

The graphs of the first and second derivatives of a function f(x) are given below, with the first graph representing the first derivative and the second graph representing the second derivative. Based upon these graphs, which of the following statements is correct?

First derivative:



Second derivative:



A) f(x) has exactly 3 relative minima, 2 relative maxima, and 4 inflection points.
B) f(x) has exactly 2 relative minima, 3 relative maxima, and 2 inflection points.
C) f(x) has exactly 1 relative minima, 2 relative maxima, and 4 inflection points.
*D) f(x) has exactly 2 relative minima, 3 relative maxima, and 4 inflection points.
E) f(x) has exactly 2 relative minima, 2 relative maxima, and 3 inflection points.
F) None of the above.

Item difficulty: B

Math 1314, Test 3, Problem 4 Objective 1

At $t = 0$, a rocket is launched from the top of a building that is 60 feet high. The rocket's height from the ground can be expressed as $h(t) = -16t^2 + 64t + 60$ where t is measured in seconds. Find the rocket's velocity when $t = 2$.

A) 1.00 feet per second
B) – 9.00 feet per second
C) 10.00 feet per second
D) – 3.00 feet per second
*E) 0.00 feet per second

Item difficulty: C

Math 1314, Test 3, Problem 5 Objective 2

Find the absolute maximum value of $f(x) = -\frac{2}{3}x^3 + 7x^2 - 12x - 2$ on the interval [0, 3].

A) $-\frac{23}{3}$

B) 7
C) 34
D) 3
E) –2
F) None of the above.

Item difficulty: B

Math 1314, Test 3, Problem 9 Objectives 1, 3, 4

A study indicated that the number of internal emails sent within a company per year is approximated by the function: $f(t) = 12.65t^2 - 8.32t + 22$
where f(t) is measured in millions of emails and t is measured in years with t = 0 corresponding to the beginning of the year 1996. At what rate was the number of emails changing at the beginning of 2001?

Free response:

Point breakdown	10 points
first derivative	4 points
second derivative	4 points
answer, correct units	2 points

Item difficulty: A

Math 1314, Test 4, Problem 1 Objective 1

A biologist is studying the growth of a strain of bacteria. When he begins the study, there are 6 thousand bacteria present in the culture. After 4 hours, there are 9 thousand bacteria in the culture. Assume that the population grows exponentially. Find the growth constant, k.

A) $k = \ln\left(\frac{2}{3}\right)$

B) $k = \frac{3}{8}$

C) $k = \frac{3}{2}$

D) $k = \frac{1}{4}\ln(\frac{3}{2})$

E) $k = \frac{1}{4}\ln(\frac{2}{3})$

F) None of the above.

Item difficulty: B

Math 1314, Test 4, Problem 2 Objective 2

Find the indefinite integral:

$$\int(-8x^2+x-2)\,dx$$

A. $\frac{1}{3}x^3+\frac{1}{2}x^2-2x+C$

B. $-\frac{8}{3}x^3+\frac{1}{2}x^2-2x+C$

C. $-16x+1$

D. $-\frac{8}{3}x^3-\frac{1}{2}x^2-2x+C$

E. $-\frac{8}{3}x^3+\frac{1}{2}x^2+C$

F. None of the above.

Item difficulty: A

Math 1314, Test 4, Problem 7 Objective 1

The velocity of a rocket is given by the function $v(t) = 4t^2 + 3t + 5$ where t is time in seconds and v(t) is given in feet per second. Find the total distance (in feet) traveled by the rocket from $t = 0$ to $t = 6$.

A) 167
B) 372
C) 370
D) 51
E) $\frac{2185}{6}$
F) None of the above.

Item difficulty: A

Math 1314, Test 4, Problem 8 Objective 1

An open top box is constructed from a sheet of material by cutting equal squares from each corner and folding up the edges. If the sheet of material measures 18 inches by 9 inches, find the dimension x which represents the length of one side of the square that should be cut off so that the volume is maximized.

a) ○ 3.80

b) ○ 1.90

c) ○ 14.20

d) ○ 13.50

e) ○ 7.10

f) ○ None of the above.

Item difficulty: B

Math 1330, Test 2, Problem 4 Objective 2

Given $f(x) = \begin{cases} x+1 & 5 \le x \\ x^2 & -1 < x \text{ and } x < 5 \\ \sqrt{-x} & x \le 1 \end{cases}$

Which of the following is a false statement?

A) If $f(x) = 25$, then $x = 24$ or $x = -25$.
B) The y-intercept is zero.
C) $f(4) = 2$
D) The domain is all Real Numbers.
E) $f(10) - f(-16) = 7$
F) None of the above.

Item difficulty: B

Math 1330, Test 2, Problem 10 Objectives 2 and 4

Simplify $\dfrac{\log_b \sqrt{\dfrac{1}{b}}}{\log_b \sqrt[a]{b}}$

where a = 8 and b = 10.

A) $-\frac{1}{8}$

B) -8

C) $\frac{1}{4}$

D) -4

E) 4

F) None of the above

Item difficulty: A

Math 1330, Test 2, Problem 16 Objective 4

Given $f(x) = \frac{1}{2-x}$

Show the graph on the axes provided.
State the domain, range, x-intercept, y-intercept, vertical asymptote and horizontal asymptote.

10 points

domain and range	
intecepts/asymptotes	0 – 4
shape	5 – 8
reflection	9 – 10

Item difficulty B

Math 1330, Test 3, Problem 3 Objective 1

Given the triangle ABC. Suppose AB = 7, AC = 19 and the measure of angle A is 45°, what is the area of the triangle?

A) $\frac{133}{3}$

B) $\frac{133}{4}$

C) $\frac{133}{2}$

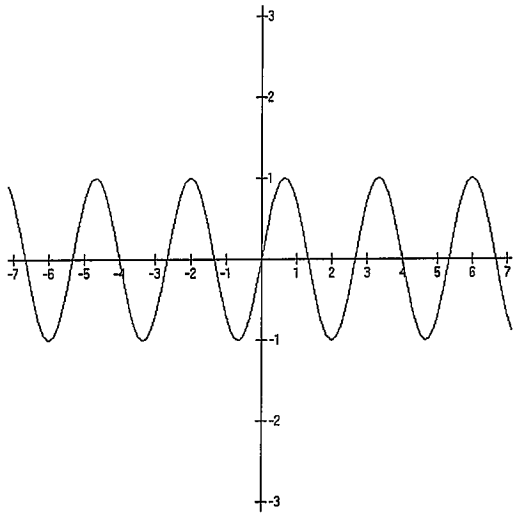
D) $\frac{133}{4}\sqrt{3}$

E) $\frac{133}{4}\sqrt{2}$

Item difficulty: C

Math 1330, Test 3, Problem 12 Objective 4

Identify the function whose graph is shown below. The point (2, –1) is on the graph.



A) $f(x) = -\sin(3x)$

B) $f(x) = -\sin(\frac{3}{4}x)$

C) $f(x) = -\cos(\frac{3}{4}x)$

D) $f(x) = -2\cos(\frac{3}{4}\pi x)$

E) $f(x) = \sin(\frac{3}{4}\pi x)$

F. None of the above.

Item difficulty: A

Math 1330, Test 3, Problem 14 Objective 3

Prove the identity: $(1 - \sin x)(\sec x + \tan x) = \cos x$

10 points

Changing to basic functions	3 points
Distribution	3 points
Arithmetic/answer	4 points

Item difficulty: A

Math 1330, Test 4, Problem 2 Objective 1

A loading dock is 15 feet high. A ramp from the ground to the top of the loading dock has an angle of elevation of 30°. What is the length of the ramp (in feet)?

A) $\frac{15}{2}$

B) $\frac{15}{2}\sqrt{3}$

C) $10\sqrt{3}$

D) $15\sqrt{3}$

E) 30

F) None of the above.

Item difficulty: C

Math 1330, Test 4, Problem 5 Objectives 3 and 4

Give the number of solutions to $\sin^2 x + 2\sin x = 8$.

A) None
B) 1
C) 4
D) 3
E) 2
F) None of the above

Item difficulty: A

Math 1330, Test 4, Problem 6 Objectives 3 and 4

Given triangle ABC with AB = x, BC = $\frac{1}{3}x\sqrt{3}$ and the measure of angle A is 30°.

How many choices are there for the measure of angle C?

A) The problem cannot be solved with the given information.
B) 3
C) 4
D) 1
E) 2
F) None of the above

Item difficulty: A

Math 1330, Test 4, Problem 9 Objective 1

Two ships leave a harbor together, travelling on courses that have an angle of 120° between them. If they each travel 3 miles, how far apart are they (in miles)?

A) $3\sqrt{2-\sqrt{2}}$

B) $3\sqrt{3}$

C) The problem cannot be solved with the given information.

D) $3\sqrt{3-\sqrt{3}}$

E) 3

F) None of the above.

Item difficulty: A

Math 1330, Test 4, Problem 13 Objectives 2 and 3

Triangle RPQ has the following information

$RQ = \frac{1}{3}\sqrt{3}$ and PQ = r. Also the measure of angle Q is 30° and R is an acute angle. Find the measure of angle R.

Law of Sines:	1 point
Filling in values:	5 points
Solving	2 points
Solution	2 points

Item difficulty: A