Physical Science Department
Student Learning Assessment

Course: Chemistry 203 (General Chemistry II) **Semester:** Spring 2012

Course Coordinator: Dr. Tracy Mitchell **No. of Students:** 62

Part 1: Exit Exam Analysis

Assessment Instrument Description: The Exit Exam consisted of 70 questions from the 2006 Second Term General Chemistry Exam, which is a timed (120 minute) multiple-choice exam, prepared by the American Chemical Society (ACS). The majority (i.e. 59/70) of the ACS examination questions are linked to the Chemistry 203 student learning outcomes (SLOs). Students were informed that 30 (or more) of the 70 questions must be correctly answered to pass the Exit Exam. After reviewing the students' scores with the course instructors, the passing score was revised to 28/70. The 59 questions that correspond to the Chemistry 203 SLOs are summarized below in Table 1 and Table 2.

Table 1: Summary of 59 Questions by Topic and SLOs

Topic	**Student Learning Outcomes** Students will solve qualitative and quantitative problems which involve:	No. of Quest.
Kinetics	1. Recalling definitions and terms relating to chemical kinetics. 3a: Predicting the impact of certain factors (concentration, temperature, catalysts, activation energy) on the rate of chemical reactions. 3b: Calculating the reaction rate given concentration and time. 3c: Relating the formation of products to the rate of disappearance of reactants given a balanced equation. 3d: Formulating rate laws from exp. data or a proposed mechanism. 3e: Recognizing the differences between first & second order reactions.	9
Equilibrium	1. Recalling definitions and terms relating to chemical equilibrium. 3f: Writing the equilibrium-constant expressions for reactions. 3h: Manipulating the equilibrium constant to reflect changes in the chemical equation. 3i: Calculating an equilibrium constant from given concentrations or pressures (or vice versa). 3j: Predicting the outcome of disrupting a system at equilibrium by changing concentrations, volume or pressure, or temperature using Le Chatlier's principle. 3s: Calculating K_{sp} from molar solubility and molar solubility from K_{sp}.	9

Topic	**Student Learning Outcomes** Students will solve qualitative and quantitative problems which involve:	No. of Quest.
Acid-Base Equilibrium	1. Recalling definitions and terms relating to acid-base chemistry. 2. Applying previous knowledge of acid-base chemistry in aq. soln. 3k: Defining and identifying Arrhenius, Bronsted-Lowry, and Lewis acids and bases. 3l: Defining, identifying, and relating (strengths) of conj. acid-base pairs. 3m: Relating (mathematically) the $[H^+]$, the $[OH^-]$, the pH and pOH of aqueous solutions using K_w and pK_w at 25°C. 3n: Calculating the pH of a strong acid, strong base, weak acid, weak base, salt, or buffer solution given initial concentrations and equilibrium constants, K_a or K_b, when appropriate. 3o: Calculating the K_a or K_b from an initial concentration and pH or from K_w for conjugate acid-base pairs. 3q: Defining and identifying buffer solutions. 3r: Interpreting and extracting the information revealed by an acid-base titration curve.	12
Solubility Equilibrium	3s: Calculating K_{sp} from the molar solubility (or vice versa).	1
Thermodynamics	1: Recalling definitions and terms relating to thermodynamics. 2: Apply previous knowledge of chemical reactions in aqueous solution (acid-base, precipitation, redox) to provide a foundation for topics focusing on chemical equilibrium and thermodynamics. 3u: Recalling the three Laws of Thermodynamics. 3v: Defining, predicting (via sign designation) and calculating (via Hess's Law or tabulated standard state values) the enthalpy, entropy, and free energy changes for reactions. 3w: Relating (mathematically) the enthalpy, entropy, and free energy changes for reactions using the Gibbs-Hemholtz equation. 3y: Relating (mathematically and theoretically) the standard free energy change and equilibrium constant for a reaction.	12
Electrochemistry	3aa: Defining and identifying oxidation, reduction, oxidizing agents and reducing agents. 3bb: Assigning oxidation numbers to isolated atoms or atoms within molecules or ions. 3dd: Identifying and defining the anode, cathode and salt bridge as applicable to voltaic/galvanic and electrolytic cells. 3ee: Ranking oxidizing agents and reducing agents by strength given standard reduction potentials. 3ff: Calculating standard cell potentials from standard reduction potentials and nonstandard cell potentials using the Nernst equation. 3hh: Relating (mathematically) the amounts of products and reactants in redox reactions to electrical charge.	11
Nuclear Chemistry	3ii: Defining the properties of alpha, beta, and gamma radiation. 3jj: Constructing and balancing nuclear equations using nuclide symbols. 3ll: Calculating the ages of objects or the amounts of radioactive nuclei remaining given the initial amount and half-life.	3
Coordination Chemistry	--	0
Laboratory Concepts	4: Draw logical conclusions from laboratory activities using the scientific method and knowledge of chemical kinetics, chemical equilibria, acid-base chemistry, selective precipitation/qualitative analysis and electrochemistry.	2

Table 2: Summary of 59 Questions by Difficulty Index

Difficulty Index*	No. of Questions	Question Difficulty
0.60 or above	19	Least Difficult
0.55 - 0.59	13	--------------
0.50 – 0.54	8	-------------
0.49 or below	19	Most Difficult

*The difficulty index is the percentage of students who responded correctly to an item.

Overview of Results

Range of Scores Possible: 0 – 70 (0% - 100%)
Range of Scores Achieved: 15 – 68 (21% - 97%)

Average Score: 36/70 (52%)
Benchmark Score: Originally: 30/70 (43%)
Modified: 28/70 (40%)

Number of Students Achieving the Benchmark Score: Originally: 49/62 (79%)
Modified: 51/62 (82%)
Number of Students Not Achieving the Benchmark Score: Originally: 13/62 (21%)
Modified: 11/62 (18%)

Table 3: Questions Answered Incorrectly by Greater Than 55% Of Students (Overview)

Question No.	Topic	% of Students with Incorrect Responses		Difficulty Index
		Wright	Nation	
2	Kinetics	63%	63%	0.37
3	Kinetics	60%	62%	0.38
4	Kinetics	60%	43%	0.57
5	Kinetics	76%	47%	0.53
14	Thermodynamics	61%	79%	0.21
28	Thermodynamics	65%	56%	0.44
33	Acid-Base Equilibrium	63%	46%	0.54
38	Acid-Base Equilibrium	61%	53%	0.47
45	Thermodynamics	76%	67%	0.33
46	Thermodynamics	77%	59%	0.41
54	Electrochemistry	84%	81%	0.19
58	Electrochemistry	58%	53%	0.47
63	Electrochemistry	60%	60%	0.40

Note: Only questions from the original set of 59 are included in Table 3 and are eligible for further analysis.

Conclusions and Recommendations: The Physical Science Department attempted to merge the Exit Exam concept, a set of questions used to verify that students have attained a minimum of essential skills from the course, and the nationally standardized American Chemical Society Examination used to gauge the skills of Wright College student against students nationwide. Although the merging of these two types of student learning assessment is not ideal, one clear benefit for students is that this format requires students to take only one exam not two during the already exam-heavy final week of the semester. Overall, the analysis of the data generated indicates that this merger was not only efficient but successful. Students averaged 36/70, which is above the original benchmark score of 30/70 and the modified benchmark score of 28/70. Furthermore, 82% of the 62 Chemistry 203 students met the modified benchmark score and passed the Exit Exam. Finally, of the 11 students failing the ACS Exit exam and not only qualifying but also sitting for the Departmental Appeals Exam, 6 students passed with a minimum score of 10/20. (Note: Two students did not opt to take the Departmental Appeals Exam.)

The 59/70 questions which relate to Chemistry 203 student learning outcomes covered the majority of Chemistry 203 topics and varied in the level of difficulty (see Tables 1 and 2). 46/59 questions were correctly answered by at least 55% of the students. A detailed question analysis was performed on the 13 questions that were answered incorrectly by more than 55% of the students.

Kinetics:

At least 55% of students correctly answered 5/9 questions relating to chemical kinetics.

- Question 2 was answered incorrectly by 63% of the Wright College students as compared to 63% of students nationwide. **This question involves interpreting various concentration versus time graphs to identify a particular rate relationships (SLO 3e).** The greatest number of students (48%) that missed this question did not recognize that the slope was negative for a first order ln[A] vs. t graph.
- Question 3 was answered incorrectly by 60% of the Wright College students as compared to 62% of students nationwide. **This question involves recognizing a rate law given the units of the rate constant and subsequently solving for the rate using the information provided (SLO 3e).** The greatest number of students (24%) that missed this question did not recognize that the reaction was second order. These students misidentified the reaction as first order.
- Question 4 was answered incorrectly by 60% of the Wright College students as compared to 43% of students nationwide. **This question involves calculating the rate of reaction given the number of reactants and products at two points in time (SLO 3b).** Students have less exposure questions involving diagrams, which require students to count the number of particles of a desired substance before calculating the reaction rate.
- Question 5 was answered incorrectly by 76% of the Wright College students as compared to 47% of students nationwide. **This question involves recognizing the effect of temperature on the reaction rate and references the terms activation energy, concentration, and energy of molecules (SLO 3a).** The distribution of incorrect answers from students was nearly equal (26%, 26%, and 24%). 52% of students incorrectly believed a common misconception: that the activation energy for a reaction is temperature dependent. Students seemed to have little understanding of the kinetic molecular theory of gases (from Chemistry 201), the collision theory, or the meaning of a reaction's activation energy.

Conclusion: When compared to students nationwide, Wright College students are similarly challenged by Questions 2 and 3. However, a greater percentage of Wright College students had difficulty with Questions 4 and 5 as compared to national norms, which suggests that SLO 3a and SLO 3b are not being fully achieved.

Recommendation: Inform Chemistry 203 instructors of the apparent weaknesses in student understanding and request greater coverage of these aspects of kinetics (summarized below). Also, encourage instructors to assign or review problems from the **Visualizing Concepts** section at the end of each chapter to expose students to types of questions encountered less frequently.

1. Graphs for first order reactions (ln[A] vs. time) exhibit negative slopes, while those for second order reactions (1/[A] vs. time) exhibit positive slopes.
2. The units of k indicate the overall order of the reaction.
3. E_a is independent of temperature.
4. Collision Theory - As the temperature of the reaction increases, the kinetic energy of the molecules increases allowing them to overcome the E_a barrier and react to form product thus increasing the reaction rate.

<u>Acid-Base Equilibrium:</u>

At least 55% of students correctly answered 10/12 questions relating to acid-base equilibrium.

- Question 33 was answered incorrectly by 63% of the Wright College students as compared to 46% of students nationwide. **The question involves calculating the pH of a solution containing a weak acid and its conjugate base in the form of a salt (i.e. a buffered solution) after the addition of HCl (SLO 3n).** The greatest number of students (24%) that missed this question knew that the pH would decrease upon the addition of a strong acid to the buffer. However, these students were unable to calculate the correct value of the pH. Another 23% of students mistakenly thought that the pH of the buffer would increase by the addition of a strong acid to the buffer.
- Question 38 was answered incorrectly by 61% of the Wright College students as compared to 53% of students nationwide. **This question involves relating (mathematically) the $[H^+]$, the $[OH^-]$, the pH and pOH of aqueous solutions using K_w and pK_w at $25^\circ C$ (SLO 3m).** The greatest number of students that missed this question (26%) did not realize that the pH of pure water is only 7.00 IF the temperature is 25°C. Equilibrium constants, which include K_w, are temperature dependent. Thus, a neutral solution does not have a pH of 7.00 unless the temperature is 25°C. Finally, another 24% realized that the pH was not 7.00 but did not correctly calculate the pH from the pK_w value. The term, pK_w, may not be used as frequently as K_w in the textbook problems or in lecture examples.

Conclusion: When compared to students nationwide, Wright College students are similarly challenged by Question 38. However, a greater percentage of Wright College students had difficulty with Question 33, which suggests that SLO 3n is not being fully achieved.

Recommendation: Inform Chemistry 203 instructors of the apparent weaknesses in student understanding and request greater emphasis on these aspects of acid-base equilibrium (summarized below). Also, encourage instructors to assign or review problems from the **Visualizing Concepts** section at the end of each chapter to expose students to questions involving molecular diagrams which are encountered less frequently.

1. When added to a buffered solution, a strong acid will slightly lower the pH of the solution and a strong base will slightly elevate the pH of the solution. The Henderson-Hasselbach equation aids in calculating the resulting pH of the buffered solution. Note: The Henderson-Hasselbach equation is not given for use on the ACS exam. It must be memorized.
2. The $pK_w = -\log K_w$ and $K_w = [H_3O^+][OH^-]$. $K_w = 1.0\times10^{-14}$ only at 25°C, which makes the pH of pure water 7.00.
3. Equilibrium constants (like K_w) are temperature dependent. Thus, pK_w values are temperature dependent.
4. Pure water does not have a pH of 7 unless the temperature is 25°C.

Note: Although Chemistry 203 has many lab activities that involve the titration of weak acids with strong bases, it does not have an activity that explores the titration of a weak base by a strong acid. An experimental activity of this type should be introduced into Chemistry 203 to expose the students to this scenario.

<u>Thermodynamics</u>: At least 55% of students correctly answered 8/12 questions relating to chemical thermodynamics.

- Question 14 was answered incorrectly by 61% of the Wright College students as compared to 79% of students nationwide. **This question requires students to select the sign (positive or negative) for ΔH and ΔS for the spontaneous dissolution of a salt (KNO_3) in water. (This question addresses SLO 3v and 3w.)** The majority of students (42%) correctly concluded the sign of entropy, but incorrectly concluded the sign of enthalpy for this dissolution process. Students are first introduced to enthalpy in Chemistry 201. Although enthalpy is reviewed in Chemistry 203, the fact that endothermic process results in its beaker becoming cold and that an exothermic process results in its beaker becoming warm is not typically revisited, which may partially explain the lower level of student achievement on this question.
- Question 28 was answered incorrectly by 65% of the Wright College students as compared to 56% of students nationwide. **This question requires students to select the sign (positive or negative) for ΔH and ΔS that would produce the largest equilibrium constant. (This question addresses SLO 3w and 3y.)** The greatest number of students (34%) that missed this question correctly concluded that a positive entropy would support a larger equilibrium constant, but incorrectly concluded that a positive enthalpy would support a larger equilibrium constant value. This question requires an understanding of ΔG° and its relationship to K as well as ΔH° and ΔS°. Students are not given the equations that relate these variables, which may be one explanation for the low performance. In addition, more conceptual problems may need to be introduced into instruction and examinations to adequately prepare students for the ACS exam.
- Question 45 was answered incorrectly by 76% of the Wright College students as compared to 67% of students nationwide. **This question requires students to interpret a plot of temperature versus time and to describe the type process indicated as endothermic or exothermic and spontaneous or non-spontaneous (SLO 3v).** The greatest number of students (47%) that missed this question correctly concluded that the process was spontaneous, but incorrectly concluded that the process was exothermic (when it was shown to be an endothermic process). Students are first introduced to enthalpy in Chemistry 201. Although enthalpy is reviewed in Chemistry 203, the fact that endothermic process results in its beaker becoming cold (indicated by the temperature of the solution decreasing) and that an exothermic process results in its beaker becoming warm (indicated by the temperature of a solution increasing) is not typically revisited.
- Question 46 was answered incorrectly by 77% of the Wright College students as compared to 59% of students nationwide. **This question requires students to apply previous knowledge of acid-base neutralization reactions (and net ionic equations) and to explain the enthalpy of reaction (SLO 2).** The greatest number of students (55%) that missed this question did not recognize that the enthalpy value for the neutralization of a strong acid by a strong base is the same because all these reactions reduce to the same net ionic equation. These students selected a correct statement ("All of these (strong) acids form weak conjugate bases and all of these (strong) bases form weak conjugate acids") but this statement was not the reason for the same enthalpy of reaction value. Students are first introduced to neutralization reactions and net ionic equations in Chemistry 201. Chemistry 203 does not typically include a review of net ionic equations.

Conclusion: When compared to students nationwide, Wright College students are similarly challenged by Questions 14, 28, and 45. However, a greater percentage of Wright College students had difficulty with Question 46 as compared to national norms, which suggests that SLO 2 is not being fully achieved. Students appear to have difficulty retaining the information introduced in Chemistry 201 relating to net ionic equations, enthalpy, and the dissolution of salts.

Recommendation: Remind Chemistry 201 instructors that thorough coverage of net ionic equations, enthalpy, and the dissolution of salts is necessary to prepare students adequately for Chemistry 203. Inform Chemistry 203 instructors of the apparent weaknesses in student understanding and request greater coverage of these aspects of thermodynamics (summarized below). Furthermore, remind instructors that the students must memorize the Gibbs-Hemholtz equation ($\Delta G = \Delta H_{system} - T\Delta S_{system}$) as it is not given for reference by the ACS exam and suggest that instructors introduce more conceptual problems involving thermodynamic relationships in their instruction and examinations to adequately prepare students for the ACS exam.

1. In an endothermic process the solution temperature decreases, which results in its beaker becoming cold. In an exothermic process the solution temperature increases, which results in its beaker becoming warm.
2. A larger value of K results from a more negative value of $\Delta G°_{system}$, which is supported by a negative $\Delta H°_{system}$ and a positive $\Delta S°_{system}$ (as indicated by the Gibbs-Hemholtz equation).
3. A larger value of K results from a more negative value of $\Delta G°_{system}$, which indicates that the reaction is spontaneous under standard state conditions.

Note: Although Chemistry 201 has a thermochemistry lab activity, Chemistry 203 does not. An experiment that not only reviews the enthalpy changes associated with neutralization reactions and dissolution processes, but also incorporates the aspects of entropy and free energy changes should be introduced into Chemistry 203.

<u>Electrochemistry</u>: At least 55% of students correctly answered 8/11 questions relating to electrochemistry.

- Question 54 was answered incorrectly by 84% of the Wright College students as compared to 81% of students nationwide. **This question requires students to understand the process of electrolysis for an aqueous salt solution (SLO 3dd and 3ee).** The greatest number of students (45%) that missed this question assumed that water would not undergo electrolysis.
- Question 58 was answered incorrectly by 58% of the Wright College students as compared to 53% of students nationwide. **This question requires students to know definitions related to electrochemistry (galvanic cell and salt bridge) (SLO 3dd).** The greatest number of students that missed this question (34%) thought that the salt bridge provided a path for the flow of free electrons. Students may have confused electrons flow with ion flow.
- Question 63 was answered incorrectly by 60% of the Wright College students as compared to 60% of students nationwide. **This question requires students to know definition of a reducing agent and identify the best reducing agent given standard reduction potentials (SLO 3aa and SLO 3ee).** The greatest number of students that missed this question (23%) incorrectly chose the worst oxidizing agent (i.e. the substance less readily reduced). Another group of students (21%) incorrectly chose the best oxidizing agent (i.e. the substance more readily reduced).

Conclusion: When compared to students nationwide, Wright College students are similarly challenged by Questions 54, 58 and 63.

Recommendation: Inform Chemistry 203 instructors of the apparent weaknesses in student understanding and request greater coverage of these aspects of electrochemistry (summarized below). Furthermore, encourage instructors to explain the difference between electrolysis of a molten salt and the electrolysis of an aqueous salt solution.

1. When an aqueous salt solution undergoes electrolysis, water may participate in the electron transfer events. The two half reactions that yield the least negative E_{cell} value upon pairing will actually participate in the electrolytic redox event.
2. The terms galvanic cell, voltaic cell, and battery are synonymous terms referring to spontaneous redox reactions marked with positive E_{cell} values.
3. In a galvanic cell the purpose of the salt bridge is to maintain charge balance in the cell by allowing cations to flow toward the cathode and anions to flow toward the anode. An external wire connects the electrodes in a galvanic cell and provides a path for the flow of electrons.
4. Stronger oxidizing agents undergo reduction and have more positive standard reduction potentials. Stronger reducing agents undergo oxidation and have more positive standard oxidation potentials.

Note: Students preformed exceptionally well on the 9 **Equilibrium** questions, 1 **Solubility Equilibrium** question, 3 **Nuclear Chemistry** questions and 2 **Laboratory Concept** questions with at least 55% of students answering each of these questions correctly.

Conclusions and Recommendations (Summary): Although 82% (of the 62) Chemistry 203 students met the modified benchmark score of 28/70 and passed the Exit Exam, the data collected indicates that emphasis on particular aspects of chemical kinetics, acid-base equilibrium, chemical thermodynamics, and electrochemistry as well as the introduction of practice questions utilizing molecular diagrams and graphs may serve to enhance student learning. The addition a laboratory activity that focuses on thermodynamic (enthalpy, entropy and free-energy) changes for neutralization reactions and dissolution processes as well as another lab activity that includes the titration of a weak base by a strong acid would further support student understanding of these concepts. Currently, Chemistry 203 does not have a thermochemistry lab activity or an acid-base lab that evaluates the titration of a weak base with a strong acid.

The data indicates that the majority of students demonstrated competency with regard to the student learning outcomes for Chemistry 203. Students appeared to have attained the strongest understanding of chemical equilibrium and the weakest understanding of chemical kinetics and chemical thermodynamics. Therefore, instructors should be encouraged to provide ample time for the instruction of chemical thermodynamics as well as ample problem-solving opportunities.

Part 2: ACS Exam Analysis

Assessment Instrument Description: The 2006 Second Term General Chemistry Exam is a 70-question, multiple-choice exam, prepared by the American Chemical Society (ACS) to assess the knowledge gained by students after completing the second semester of the General Chemistry sequence (i.e. Chemistry 203). Composite norms provided by ACS for this exam are based on the scores of 1,315 students in 16 colleges.

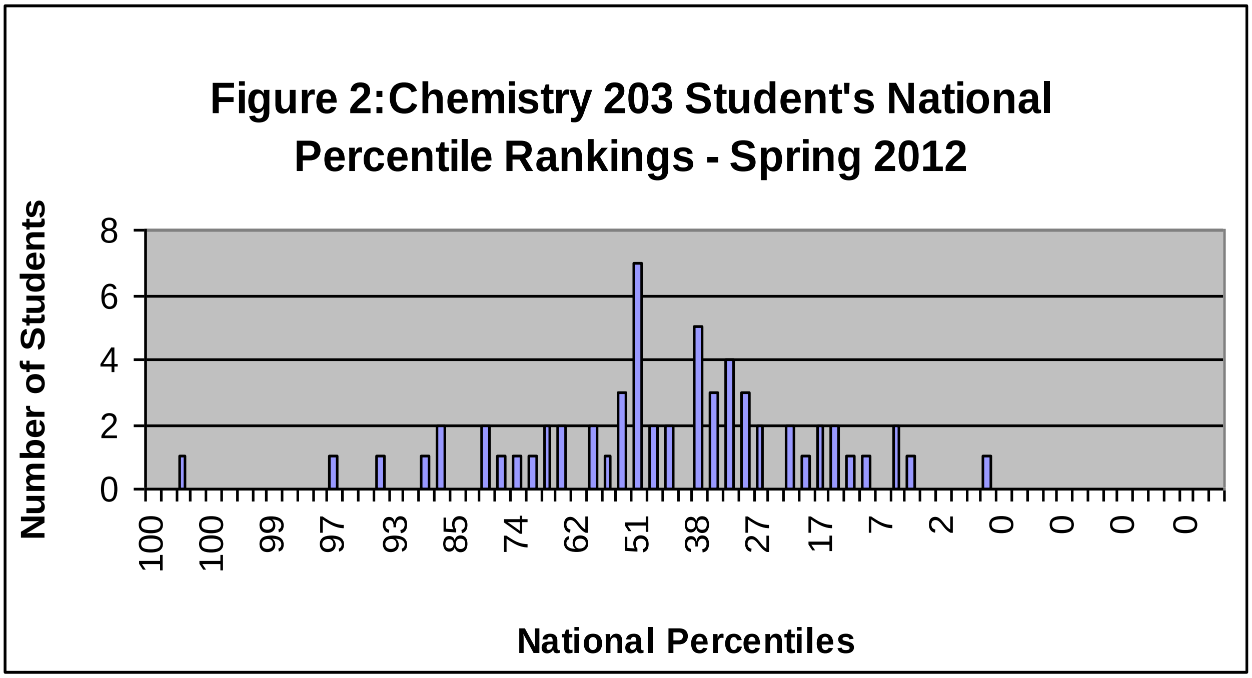
Range of Scores Possible: 0 – 70 (0% - 100%)
Range of Scores Achieved: 15 – 68 (21% - 97%)

Average Score: 36/70 (52%)
National Average Score: 38/70 (54%)

Number of Students Achieving the National Average: 28/62 (45%)
Number of Students Not Achieving the National Average: 34/62 (55%)

Table 7: Summary of Chemistry 203 Student Achievement

Score	National Percentile	Number of Chem 203 Students
53 - 70	90 - 100	3
48 - 52	80 - 89	5
45 - 47	70 - 79	3
41 - 44	60 - 69	6
38 - 40	50 - 59	11
35 - 37	40 - 49	4
31 - 34	30 - 39	15
28 - 30	20 - 29	4
24 - 27	10 - 19	6
0 - 23	0 - 9	5



Summary: As evidenced by the data in Table 7 and Figure 2, 28/62 (i.e. 45% of the) Chemistry 203 students scored at or above the national average. In fact, three students scored above the 90th percentile. Likewise, 34/55 (i.e. 55% of the) students scored below the national average with five students scoring below the 10th percentile. Figure 3 illustrates the Chemistry 203 Student Score Distribution from Fall 2011.