Harold Washington College
Assessment Committee

2008 Gen Education Natural Science Assessment Report

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I. EXECUTIVE SUMMARY

This document presents Harold Washington College's (HWC) assessment of the Natural Science general education objective that states that students will be able to "understand the major principles of the natural sciences and the application of the scientific method to biological, physical, and environmental systems." The report comprises information about the process of choosing, administering and generating results about of the science assessment.

During the fall 2006, the Assessment Committee (AC) initiated the re-evaluation of the Natural Sciences General Education Objective. The General Education Math and Science subcommittee (GEMS) was charged with this process that involved writing the definition for this objective and the student learning outcomes (SLOs). On October 31, 2007, the AC approved the definition and student learning outcomes. GEMS focused the attention on assessment of the process of science as the central theme of the Natural Sciences General Education Objective. Several assessment tools, within the affective domain, were considered with respect to perceptions of the process of science. It was ultimately decided on the general science version of the Epistemological Beliefs Assessment for Physical Science (EBAPS). EBAPS, a freely-accessible survey, was written by Andrew Elby in the Department of Physics at the University of Maryland. The decision to use EBAPS was based on the following criteria: alignment with the approved SLOs, appropriateness for HWC's student population, accessibility, and ability to be completed within a class period. The general science version EBAPS was complemented with a demographic survey that was adapted from the Humanities (*Hummm*) assessment. These two integrated surveys constituted what is considered the Natural Science Assessment Tool for HWC.

The demographic survey was used as an introduction to the Natural Science Assessment Tool, and was adapted and improved from the demographic survey used in the Humanities Assessment. The demographic survey ask vital questions for the statistical analysis and separates the results for students who had only studied at HWC, from those whose natural science studies were done at other institutions. It also determines whether the sample of students that took the assessment is demographically representative of the student body registered for the semester; and furthermore, it intend to record the students' interests, values, and opinions related to the Natural Sciences.

The general science version of EBAPS contains 30 statements that assess students' views along five non-orthogonal epistemological axes:

1. Structure of scientific knowledge.
2. Nature of knowing and learning.
3. Real-life applicability.
4. Evolving knowledge.
5. Source of ability to learn.

The general science version added 2 statements to evaluate a sixth item called "Concepts" that will be presented in this report as axis 6 to facilitate interpretation. According to the author, EBAPS is designed to probe students' epistemologies, views about the nature of knowledge and learning in the physical sciences that may affect students' learning behavior. It is appropriate for assessing conceptual courses for the liberal arts.

The AC was able to align the EBAPS'32 statements to the following four HWC's SLOs defined for the Natural Sciences assessment:

1. Formulate reasonable explanations of natural phenomena based on thorough observations.
2. Interpret and articulate scientific results that are presented in verbal, graphic and/or tabular form.
3. Critically evaluate scientific resources and scientific claims presented in the media.
4. Apply steps of the scientific method to solve problems.

In spring 2008, the Natural Science Assessment tool was piloted in four class sections, including Business, Chemistry, Child Development, and Physical Science. As a result of the successful pilot, some presentation adjustments were done to the tool and the Natural Science assessment was administrated college wide during the week of October 20 to 24, 2008. The assessment was completed by 845 students from 46 sections that were volunteered by 36 faculty members. After discharging 14 questionnaires that were found to have more than 5 blank answers, the sample of assessed students represents 10.9% of the total enrollment for the fall 2008 semester. As a whole this percentage is found to be statistically consistent with, and so representative of, the for-credit, on-campus student population of that semester.

The study of the statistical report of the results in aggregate (for 831 students), for each of the 13 questions of the demographic survey and every one of the 32 statements of EBAPS shows the following results:
72% of the students reported to be full time. 60% of them are females, 66% are younger than 25 years old. The predominant race is African-American (34%), followed by Hispanic (29%), white (21%), Asian-American (9%), multiracial (4%), while Arabs and Native Americans are less than 1%.

The statistics also show a good response and a positive attitude toward science with 74% of the students feeling comfortable with science, 17% indicating that they are “highly comfortable” and 57% are “comfortable”. The students also reported high levels of comfort with math (60%), arts (85%), writing (82%) and reading (91%). Similarly, ~50% agreed to some degree that the study of science has useful applications to their every-day lives, helps them to become more rational and logical, gives them important skills that they can use in other classes, and influences them to read science books. 14% recognized that taking science classes has helped them achieve their goals, 18% thought that they have broadened their scientific interests, and ~10 to 15% recognize science’s connection with religion, society and politics.

These results also show that students’ behavior towards science is very positive. Compared to the time before the surveyed students came to HWC, 52% agree that they are more likely to read different types of books; 40% agree that they are more likely to read scientific articles; 56% agree that they are more likely to discuss life’s big questions; 57% feel confident about understanding what they read, see, and hear. 12% visited the Museum of Science and Industry, Planetarium, Aquarium, or the Field Museum; 40% attend a film presentation of a science-related documentary; 8% went a science-related event; 10% go to a science-related lecture or educational presentation; 9% debate on a scientific subject (i.e. climate change). However, only 30% would have taken science classes even if they were not required. These results show a disconnection between the level of comfort and the attitude towards science and their cognitive skills.

In past assessments, up to 40% of the students have failed to answer questions that are critical in the regressive analyses. Only up to 2.4% the students assessed with the natural science assessment tool at HWC failed to answer these questions leaving the sample statistically consistent, and representative of the on-campus student population. These questions allow the separation of the sample into three subpopulations: 1) students who have taken 0 natural science classes, 2) students who have taken 1 to 2 natural science classes, and 3) students who have taken 3 or more science courses.

According to the analyses applied to these 3 subpopulation, the students' performance in natural science shows significant improvement as the students progress in their science education level. In overall, students' performance changed from an overall mean score of 47% among students who have taken 0 natural science courses to 55% among students who have completed 3 or more natural science courses at HWC. The analysis of these results shows the evolution of students' thinking in relation to the EBAPS axes and the HWC's SLOs.

A detailed evaluation of the results shows that the students' demonstrate significant learning gains in 4 out of the 6 EBAPS axes and in 3 of the 4 HWC- SLOs. Student scores across the three levels of natural science education show improvement for Axis 1 (structure of scientific knowledge), the second axis, nature of knowing and learning, and Axis 5 -Source of Ability to Learn. The most significant improvement is Axis 3 - real-life applicability. Axes 4 and 6 show a trend of improvement that was not supported by a significant level of confidence.

SLO 1, formulate reasonable explanations of natural phenomena based on thorough observations, and SLO3, critically evaluate scientific resources and scientific claims presented in the media, exhibits significant improvement in performance. SLO 4, applying steps of the scientific method to solve problems, exhibited highly significant learning gains. While SLO 2, interpret and articulate scientific results that are presented in verbal, graphic and/or tabular form, is a particularly unique category because it includes only two questions. These results can signify that the students need re-enforcement in these features represent by axes 4 and 6 and SLO 2 or can also be explained due that the number of EBAPS statements that assess each of these categories, they are less than those associated to the other axes and SLOs.

Similar results are also obtained by applying the ad hoc analysis (Tukey's HSD) to the data to establish the rate of improvement (slope) between the subpopulations defined for the sample (Tables 12 and 13). It was found that students who have taken 1-2 natural science classes improve greatly when they take 3+ classes. This rate of improvement is higher than that established between the students that have taken 0 and 1 to 2 for all subscales that show significant differences. Therefore, the aggregated value of learning from taking 3 or more natural science courses seems to be greater than the added value of transitioning from no science to 1-2 courses.

II. HWC NATURAL SCIENCE ASSESSMENT PROCESS

To accomplish its mission, Harold Washington College (HWC) provides liberal arts career education, sustains an optimum learning and working environment, emphasizes knowledge as one of the College's seven essential values and gathers and uses assessment information to improve student learning (HWC, 2009,). Within this framework, the Assessment Committee (AC) is charged with assessing the fulfillment of the College's seven General Education Objectives and their specific student learning outcomes (SLOs). In doing so, the AC collects, reviews, analyzes, and disseminates data on the educational experiences of the college community, in an effort to fulfill the mission of the College to maintain high standards for learning quality and, ultimately, improve student learning.

This report documents HWC's assessment of the General Education Objective #5 (Natural Science) that states that students will be able to "***understand the major principles of the natural sciences and the application of the scientific method to biological, physical, and environmental systems."*** (HWC, 2009). The report comprises information about the process that involve choosing an appropriate assessment tool for the HWC student body, the institutional administration of the assessment, the scoring, the results, conclusions and recommendations.

The process conducive to the administration of the Natural Science Assessment at HWC has been summarized from information obtained from the NCA Progress Report on Assessment of Student Learning Outcomes for General Education Objectives[1], the GEMS Report of Science Tool selection[2], and a summary of recent developments. The history will be structured within the 6-stage assessment process defined in the AC webpage[3] and presented below.

Stage One – Outcome Definition:

During the fall 2006 semester, the AC focused its attention to the Natural Sciences General Education Objective, a process that involved writing the definition and four SLOs for this objective. Initially, the AC formed a subcommittee for General Education Math and Science (GEMS). This interdisciplinary committee was integrated by Chao Lu and Chris Sabino from Math; Liliana Marín and Dana Perry from Physical Sciences; Carrie Nepstad from Child Development, and Glenn Weller from CIS. The AC also requested the Biology and the Physical Science Departments to assist the subcommittee in completing a definition and student learning outcomes suitable for both departments. Accordingly, this process included the inputs of the Physical Science and Biology department chairpersons at the time, Mike Davis and Cheryl Dias respectively.

To make an informed decision, GEMS reviewed the outcomes of other community colleges, such us Mesa, Tacoma, and College of Mount St. Joseph. It was challenging to write a definition that would incorporate the disparate disciplines within the natural sciences (e.g., life sciences such as biology, botany, zoology and physical science such as chemistry, physics, and geosciences). Yet, on November 29, 2006, Dana Perry and Liliana Marín, faculties of the Physical Science Department and members of the AC, submitted a draft of the definition and SLOs to the AC that where finally approved on October 31, 2007 as follow:

Definition: ***"The Natural Sciences encompass the life sciences (Biology, Zoology, and Botany) and the physical sciences (Physics, Chemistry, and Earth Sciences - Geology, Meteorology Oceanography and Astronomy). The Scientific Method is the process used to explore nature, and it is based on observations, predictions, experimental investigations, and theoretical explanations of natural phenomena. Application of the scientific method reveals patterns in the observed phenomena, which leads to the fundamental concepts, theories, and laws of the life and physical sciences".***

[1] Nepstad, C. *Progress Report on Assessment of Student Learning Outcomes for General Education Objectives*. (Proposed for the Higher Learning Commission, a Commission of the north Central Association of Colleges and Schools, Nov 30, 2006).
[2] Perry, D. *Progress Report GEMS Report of Science tool selection* (Internal report to the Assessment Committee, May, 2008).
[3] http://faculty.ccc.edu/colleges/hwashington/assessment/Framework.html, 2009.

Student Learning Outcomes: "Students who satisfactorily complete the Natural Science classes at HWC will be able to:

1. ***Formulate reasonable explanations of natural phenomena based on thorough observations.***
2. ***Interpret and articulate scientific results that are presented in verbal, graphic and/or tabular form.***
3. ***Critically evaluate scientific resources and scientific claims presented in the media.***
4. ***Apply steps of the scientific method to solve problems".***

Additionally, a change to the Natural Sciences General Education Objective was also proposed. This proposal replaces the present Natural Science General Education Objective that states that students will be able to "***understand the major principles of the natural sciences and the application of the scientific method to biological, physical, and environmental systems"*** with an objective that reads that students will be able to***" apply the scientific method to biological, physical, and environmental systems."*** This change is based on the fact that students earning an AA degree at the college are not necessarily exposed to **"**major principles of the natural sciences" as it was stated in the objective.

To earn an AA degree, students need to complete two science courses, one life and one physical science, one of which needs to include a laboratory. Due to the variety of science classes offered at the college, the students fulfill the general education natural sciences requirement to earn an AA degree by taking any combination of life and physical science classes. In this arrangement, the students can be exposed to completely different disciplines and may have different ideas of the "major principles of science" according to those disciplines. However, regardless of the discipline, the students are always exposed to the scientific method through those courses. For this reason, GEMS emphasized that an important component to the objective is that science involves a process, the scientific method, which includes observation, experimentation, and explanation of a natural phenomenon. Consequently, this process is stated in the approved definition, the SLOs, and is a support of the proposed change to the objective. Although there has not been a change in the Natural Science Objective the proposal still remains open for future discussion to have a more attainable goal in the Natural Sciences.

Stage Two – Assessment Research and Design:

With the process of science (scientific method) as the central theme for the definition and SLOs for the Natural Sciences General Education Objective, GEMS focused on an assessment tool that could assess science as a process. Initially, GEMS planned to design a homemade tool to meet these criteria, using the Humanities (Hummm) assessment tool as a model. The tool would include three articles from three different science disciplines (e.g. Physical Science, Environmental Science, and Biology), and the students would choose to answer the questions from one of the disciplines. However three challenges became apparent in the process due to the multiple science disciplines in which students could be enrolled at the college: 1) Choosing fair articles seemed problematic; 2) the classes' variability makes the process of writing appropriate questions difficult, and 3) there were expressed concerns for validity and reliability of the tool.

After these realizations the AC decided on a change in direction toward considering an attitudinal survey that assessed the affective domain, with respect to perceptions of the process of science. Several assessment tools were considered and evaluated in light of the criteria set by the AC for choosing an assessment tool: 1) Aligns with the approved student learning outcomes; 2) is appropriate for the HWC student population; 3) provides useful data; 4) is time efficient (fits within a class period); and 5) is readily accessible.

The website for the University of Maryland Physics Education Research Group provides a list of attitude surveys in physics and science, including EBAPS and VASS. Table 1 summarizes the tools considered by the committee and the reasons for rejecting them as a viable tool for assessment in HWC.

Table 1. Summary of attitudinal assessment tools considered by HWC-AC for the assessment of the Natural Science General Objective and SLOs.

Tool Considered	Reasons for rejection
In-house tool	1) Choosing fair articles seemed problematic; 2) The variety of the disciplines in natural science makes the process of writing appropriate questions difficult 3) Validity and reliability are questionable
Collegiate Assessment of Academic Proficiency - **CAAP**	1) Content-specific. 2) Not aligned to HWC-SLO's. 3) Answers based on readings that were difficult to comprehend for the audience in HWC. 4) Science as a process is not approached. 5) Very long.
Views About Science Survey **VASS**	1) Focused only on physics. 2) Difficult format to follow
Thinking about Science Survey Instrument - **TSSI**	1) Very long. 2) All Likert scale
Mesa Community College Scientific Inquiry Assessment	1) Content-specific 2) Contained complex graphs and difficult to read, not appropriate for the audience in HWC.

After thoughtful analyzing and committee testing of the tools, the AC agreed on the ***general science version*** of the ***Epistemological Beliefs Assessment for Physical Science*** (**EBAPS**). This tool was written by Andrew Elby in the Department of Physics at the University of Maryland. The tool consists of a survey that measures the beliefs students hold in both science knowledge and in the process of learning science. The decision to use EBAPS was based on its fulfillment of the AC criteria for an assessment tool previously mentioned.

In HWC, the general science version of EBAPS was complemented with a demographic survey, adapted from the *Hummm* assessment. These two integrated surveys constituted what is considered in HWC the **Natural Science Assessment tool** (Appendix 1). Both EBAPS and the adapted demographic survey will be discussed in detail in the following chapter.

<u>Stage Three - Pilot Assessment Tools and Processes</u>:
In April of 2008, the Natural Science Assessment tool was piloted in four class sections that included Business, Chemistry, Child Development, and Physical Science. This pilot generated the following results:

1. The Natural Science Assessment could be completed in less than one hour; most students answered the questions in 40 minutes. Anecdotal student responses indicated that the length of the assessment

2. The choices listed as answers to two questions (#10 and #12) in the demographics survey were incorrect. This problem was rectified for the College assessment in fall 2008.

Stage Four – Administer Specific Assessment:
As a result of the successful pilot during the spring semester in 2008, the Natural Science assessment tool was administrated college wide during the week of October 20 to 24, 2008. Faculty members across the college were asked to volunteer classes to take the assessment. Thirty six faculty members volunteered their courses, and 46 credit-classes were picked. There was an imbalance between the number of 100 and 200-level classes volunteered. However, the chosen classes included all the academic departments from the college, and cover the entire schedule from Monday to Saturday.

Materials were distributed to the 46 chosen instructors, explaining the nature and goals of the assessment and student participation. The assessment was completed during regular class times by a total of 845 students, with an average response rate of 19 completed surveys per class. Out of the total of surveys, 512 came from twenty-seven 100-level classes and 369 from nineteen 200-level classes.

Although 845 students took the science assessment, 831 were considered for the calculations and results; 14 questioners were discharged since they had 5 or more blank responses. Taking the 7,748 credit student enrollment for the fall 2008 semester, 831 students represent a sample size of 10.9%. This value is above the required 10% for the accuracy of the sample to be considered statistically consistent and it is considered to be representative of the for-credit and on-campus student population of that semester.

Stage Five – Data Analysis:
Once assessment week was over, the assessment committee members from each department collected the respective surveys and housed them for a while at the AC Chairperson's office. In May 2009, Christopher Kabir from the Office of Research and Planning trained two AC members (Liliana Marín and LaRhue Finney) who were specially assigned to scan the surveys into a main database (Remark Office 6.0). By June 2009, after the process was finished, Christopher produced the Science Assessment Item Analysis Report-Fall 08. This is an overall statistical report documenting the outcome, in aggregate, for each question from the combined surveys (Appendix 2). Along with this report, Christopher generated a preliminary scoring spreadsheet of data that accompanied the general education EBAPS analysis. These documents were given to the AC members (Liliana Marín and Jaime Millán, professors from the Physical Science Department) who along with Kurt Sheu (Math Department) were specially assigned to write this report. The results of these analyses will be discussed in Chapter 4 of this document.

Stage Six – Supporting Evidence-Based Change:
This report is the first step of this stage. Once it has been reviewed and approved by the AC, the main findings and results will be broadly advertised at the college and district level. The recommendations for improving student learning will be shared and discussed in conference in and out of the college. Hopefully these findings will complement the departmental missions and assessment plans. Also, the results from the general education EBAPS analysis will be shared with the EBAPS author Dr. Andrew Elby to compare and relate his findings with those at the college.

III. NATURAL SCIENCE ASSESSMENT TOOL

As explained in stage 2 of the Natural Science assessment process, the Natural Science Assessment tool presented in Appendix 1 consists of two components: the demographic survey and the general science version EBAPS. These combined surveys, with a total of 45 questions, offered a very powerful tool to assess the SLOs associated with the General Education Objective #5 concerning Natural Science. Below is a brief explanation of both surveys.

A. Demographic Survey

The demographic survey was used as an introduction to the Natural Science Assessment Tool, and was adapted and improved from the demographic survey used in the Humanities Assessment in spring 2007. This section of the tool has 13 questions and covers the first 1½ pages of the tool (Appendix 1).

The first 8 questions are demographic inquires. The first 4 of them (1 to 4) are vital questions for the analysis that separates the results for students who had only studied at HWC from those whose studies were conducted at other institutions. The last 4 questions of this part of the survey (5 to 8) are used to determine whether the sample of students that took the assessment is demographically representative of the student body registered for the semester in terms of sex, race/ethnicity, age, and academic status. Collection of this information ensures reliability of the data assessed.

Questions 9 to 13 intend to record the interests, values, and opinions related to Natural Sciences. Question 9 indicates a comfort level with science ranging from highly comfortable to highly uncomfortable. Questions 10, 11, 12 measure attitudes and require a Likert-scale response, ranging from strongly disagree to strongly agree. Question 13 assesses behaviors, asking the students about how much their behavior, such as attending shows, museums, presentations and debates concerning science have changed since they came to HWC. The overall statistical report documenting the outcomes for these questions is found in Appendix 2. The analysis of the results will be found in Chapter 4.

B. EBAPS Overview

The overview of EBAPS has been summarized from information obtained from the EBAPS Home Page[4 5] converted in the document: Epistemological Beliefs Assessment for Physical Science (EBAPS) contained in Appendix 3. According to this document, "EBAPS is an instrument designed to probe students' *epistemologies*, views about the nature of knowledge and learning in the physical sciences that may affect students' learning behavior. It was initially developed and validated by Andrew Elby, John Frederiksen, Christina Schwarz, and Barbara White at the University of California, Berkeley."

There are two different forms of the EBAPS tool: 1) The physics version and 2) The general science version, adopted by HWC for the Science Assessment. This version, which contains 32 questions, is described by the author as "suitable for purely conceptual courses for the liberal art". EBAPS complies with the criteria of a satisfactory assessment tool depicted in stage two of the assessment process in the previous chapter. In addition to being readily available and appropriate for the audience at HWC, the most important criterion is that the questions focus on the process of science rather than conceptual details of particular science disciplines and can be aligned to the approved science SLOs, as it will be shown in Chapter 4.

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[4] EBAPS Home: http://www2.physics.umd.edu/~elby/EBAPS/home.htm

[5] The Ideas behind EBAPS http://www2.physics.umd.edu/~elby/EBAPS/idea.htm

The EBAPS survey is presented in the science assessment tool from the second half of the second page to the end of page 4. The general science version of EBAPS contains 32 statements, divided into 3 parts: the first part, statements 1 to 22, require a Likert-scale response ranging from strongly disagree to strongly agree, consistent with the questions that assess attitude in the demographic survey. The Likert-scale questions are easily readable and are typically one to two typed lines in length. Part two encompasses statements 23 to 27; this offers multiple-choice answers. The third group includes statements 28 to 32; each statement simulates a conversation between two people where they state their position about a hypothetical science situation. The students are offered with multiple-choice answers agreeing in some level with one or the other. In these questions, students are able to relate to the dialog because they are written with a conversational tone.
According to the EBAPS homepage, this instrument contains 30 statements that assess students' views along five non-orthogonal epistemological dimensions: "axes or subscales"[4],and 2 more statements to evaluate a sixth item called "Concepts" that will be called in this report axis 6 to facilitate interpretation. Table 2 presents the alignment between EBAPS statements and the axes, provided by Dr. Elby. The description of these axes, according to the EBAPS web page, is as follows:

1. "*Structure of scientific knowledge. Is physics and chemistry knowledge a bunch of weakly connected pieces without much structure and consisting mainly of facts and formulas? Or is it a coherent, conceptual, highly-structured, unified whole?*
2. *Nature of knowing and learning. Does learning science consist mainly of absorbing information? Or, does it rely crucially on constructing one's own understanding by working through the material actively, by relating new material to prior experiences, intuitions, and knowledge, and by reflecting upon and monitoring one's understanding?*
3. *Real-life applicability. Are scientific knowledge and scientific ways of thinking applicable only in restricted spheres, such as a classroom or laboratory? Or, does science apply more generally to real life? These items tease out students' views of the applicability of scientific knowledge as distinct from the student's own desire to apply science to real life, which depends on the student's interests, goals, and other non-epistemological factors.*
4. *Evolving knowledge. This dimension probes the extent to which students navigate between the twin perils of absolutism (thinking all scientific knowledge is set in stone) and extreme relativism (making no distinctions between evidence-based reasoning and mere opinion).*
5. *Source of ability to learn. Is being good at science mostly a matter of fixed natural ability? Or, can most people become better at learning (and doing) science? As much as possible, these items probe students' epistemological views about the efficacy of hard work and good study strategies, as distinct from their self-confidence and other beliefs about themselves."*

The scoring of the results of EBAPS is automatically done and it is obtained feeding the results into a Microsoft Excel spreadsheet template given by Dr. Elby and developed by Davidson College. In the scoring template each row corresponds to each student that took the science assessment, and each column is an EBAPS statement labeled from 1 to 32. These columns are populated with the students' raw answers to each of the 32 statements. In the HWC science assessment, the matrix has 845 rows (number of students that took the assessment), each with 32 EBAPS statements. The scale of the scoring is: 1 for an answer that "strongly" or "somewhat" agrees with the "expert", and 0 for neutral or non-expert response. As soon as the data is entered into a spreadsheet the program calculates the results. The template with the summary of the results in the EBAPS survey from the Natural Science Assessment is presented in Table 3.

Table 2. Relationship between the EBAPS axes and the statement numbers in the survey, taken from the EBAPS web page.

"Axes"	EBAPS Survey Questions					
Structure of Knowledge	*5*	10	13	15	27	30
Nature of Learning	1	14	18	19	23	32
Reality	*3*	11	20	22	29	
Evolving Knowledge	8	31				
Source of Ability to Learn	*6*	12	26	28		
Concepts	*2*	7				

Table 3: Summary of the results obtained in the EBAPS survey from the Natural Science Assessment

A: Experts Response Choices
B: # Of Completed Answers in the Natural Science Assessment that are exactly as the experts' response
C: % Responses Choices from Completed Answers in the Natural Science Assessment that are exactly as the experts' response, and other statistics considered in the EBAPS
D: Relationship between the EBAPS Axes with the question numbers in the survey

	Question Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
A	ExpertResponse1	A	A	D	D	A	A	A	A	A	A	A	D	A	D	A	A	D	D	A	A	D	D	A	D	A	A	A	D	A	D	C	D
	ExpertResponse2	B	B	E	E	B	B	B	B	B	B	B	E	B	E	B	B	E	E	B	B	E	E	B	E	B	B	B	E	B	E		E
	NeutralResponse	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C		C

	Responses Choices	# Of Completed Answers in the Natural Science Assessment																															
B	"A"	243	163	36	29	40	329	268	174	199	123	160	31	223	28	91	144	55	131	98	317	38	44	225	77	239	249	215	93	312	74	180	250
	"B"	283	202	60	47	104	181	205	228	203	224	147	62	187	73	138	200	86	197	143	175	47	44	334	187	175	194	116	204	203	125	133	174
	"C"	136	215	244	154	240	177	186	294	222	206	256	221	246	258	262	290	269	282	266	213	204	242	196	158	369	303	222	170	173	185	210	214
	"D"	124	182	280	289	301	95	109	98	153	181	150	284	116	269	209	117	256	160	171	76	263	243	53	203	29	59	192	198	101	210	131	106
	"E"	45	67	212	309	142	49	58	35	50	93	113	234	55	196	126	80	161	60	149	50	276	255	17	197	15	25	81	163	42	236	176	85

	% Responses Choices	# Of Completed Answers in the Natural Science Assessment																															
C	"A"	29	20	4	3	5	40	32	21	24	15	19	4	27	3	11	17	7	16	12	38	5	5	27	9	29	30	26	11	38	9	22	30
	"B"	34	24	7	6	13	22	25	27	24	27	18	7	22	9	17	24	10	24	17	21	6	5	40	22	21	23	14	25	24	15	16	21
	"C"	16	26	29	19	29	21	22	35	27	25	31	27	30	31	31	35	32	34	32	26	25	29	24	19	44	36	27	20	21	22	25	26
	"D"	15	22	34	35	36	11	13	12	18	22	18	34	14	32	25	14	31	19	21	9	32	29	6	24	3	7	23	24	12	25	16	13
	"E"	5	8	25	37	17	6	7	4	6	11	14	28	7	24	15	10	19	7	18	6	33	31	2	24	2	3	10	20	5	28	21	10
	Question Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
	% of Dis(A/B) resp (#27 B/E)	63	43	11	9	18	62	56	48	48	42	37	12	49	12	27	41	17	39	29	59	10	10	67	31	49	53	24	35	61	24	37	51
	% of Agree(D/E) resp (#27 A/C	20	30	59	72	53	18	20	16	25	33	31	62	21	55	40	23	50	26	38	15	64	59	8	47	5	10	52	43	17	53	37	23
	"Expert" response	Dis	Dis	Ag	Ag	Dis	Dis	Dis	Dis	Dis	Dis	Dis	Ag	Dis	Ag	Dis	Dis	Ag	Ag	Dis	Dis	Ag	Ag	A,B	D,E	A,B	A,B	A,B	D,E	A,B	D,E	C	D,E
	% "Expert" response	63	43	59	72	18	62	56	48	48	42	37	62	49	55	27	41	50	26	29	59	64	59	67	47	49	53	40	43	61	53	25	23
	% Neutral	16	26	29	18	29	21	22	35	26	24	30	26	29	31	31	35	32	33	32	25	24	29	23	19	44	36	23	20	21	22		26
	"Axes"	Nat	Con	Rea		Str	Sou	Con	Evo		Str	Rea	Sou	Str	Nat	Str			Nat	Nat	Rea		Rea	Nat			Sou	Str	Sou	Rea	Str	Evo	Nat

	"Axes"	Avg % "Exper	Avg % neutra	Questions											
D	Structure of Knowledge (Str)	38	26	*5*	18	10	42	13	49	15	27	27	40	30	53
	Nature of Learning (Nat)	44	27	1	63	14	55	18	26	19	29	23	67	32	23
	Real-life applicability (Rea)	55	27	*3*	59	11	37	20	59	22	59	29	61		
	Evolving Knowledge (Evo)	37		8	48	31	25	(#31 only has one "expert" choice)							
	ource of Ability to Learn (So	55	26	*6*	62	12	62	26	53	28	43				
	Concepts	50	24	*2*	43	7	56								

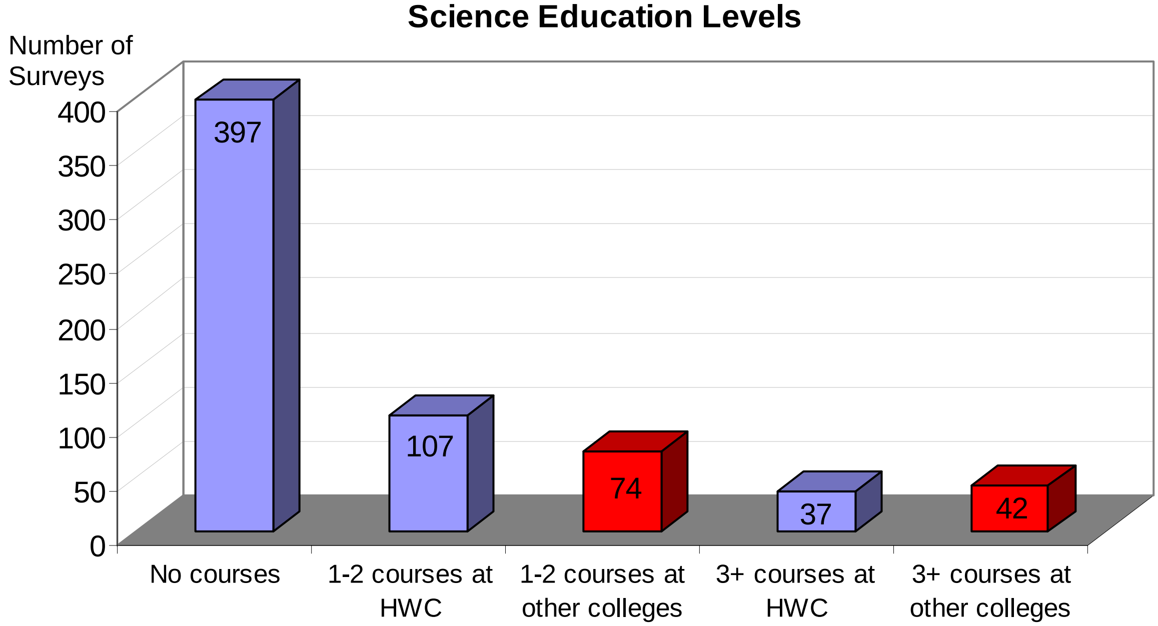
IV. RESULTS AND DISCUSION

The results of the Science Assessment Instrument encompass information from the demographic and the EBAPS surveys. As mentioned before, 845 students participated in the science assessment; however, 831 were considered for the calculations and results, since 14 questioners were found to have 5 or more blank responses. Appendix 2 shows the statistical report of the results in aggregate (for 831 students), for each of the 13 questions of the demographic survey and the 32 EBAPS statements.

In the past, up to 40% of the students have failed to answer questions vital for the analysis that separates the results for students who had only studied at HWC from those whose studies were conducted also at other institutions. In response to this difficulty, the demographic survey included four separate questions (questions 1 to 4) where the students were asked: 1) the number of credits they had completed at HWC, 2) the number of credits the student had completed elsewhere, 3) the number of Natural Science courses at HWC, and 4) the number of Natural Science courses completed at another college/university respectively. The study of the overall Science Assessment Item Analysis Report (Appendix 2) shows that as a result of this separation students were more responsive. Only up to 2.4% of the students failed to answer these questions. This makes the sample assessed statistically consistent, and representative of the on-campus student population. Figure 1 shows the breakdown of students that have not taken natural science classes and those whose science classes have been completed at HWC or other institutions in blocks of one to 2 classes and three or more.

The study of the statistical results shows that the sample of assessed students is demographically representative of the student body register during fall 2008 semester. 72% of the students reported to be full time. 60% of them are females, 66% are younger than 25 years old. The predominant race is African-American (34%) followed by Hispanic (29%), white (21%), Asian-American (9%), multiracial (4%), while Arabs and Native Americans are less than 1% (Appendix 2).

Figure 1. Unduplicated Breakdown of Surveyed Students' Natural Science Education Levels



The statistics also show a good response and a positive attitude toward science with 74% of the students feeling comfortable with science, 17% of which indicate that they are "highly comfortable" and 57% are "comfortable". The students also reported high levels of comfort with math (60%), arts (85%), writing (82%) and reading (91%). Similarly, ~50% agreed to some degree that the study of science has useful applications to their every-day lives, helps them to become more rational and logical, gives them important skills that they can use in other classes, and influences them to read science books. 14% recognized that taking science classes has helped them to achieve their goals, 18% thought that they have broadened their scientific interest, and ~10 to 15% recognize science's connection with religion, society and politics.

According to these results student behavior towards science also had a very positive outcome. Compared to the time before the surveyed students came to HWC, 52% agree that they are more likely to read different types of books; 40% agree that they are more likely to read scientific articles; 56% agree that they are more likely to discuss life's big questions; 57% feel confident about understanding what they read, see, and hear. 12% visited the Museum of Science and Industry, Planetarium, Aquarium, or the Field Museum; 40% attended a film presentation of a science-related documentary; 8% attended a science-related event; 10% attended a science-related lecture or educational presentation; 9% debated on a scientific subject (i.e. climate change). However, only 30% would have taken science classes even if they were not required. These results show a disconnection between the level of comfort and the attitude towards science and their cognitive skills.

HWC students' performance, regardless of an interaction effect from taking science courses at other institutions, showed statistically significant improvement (Figure 2). Students' performance changed from an overall mean score of 47% among students who have taken 0 natural science courses to 55% among students who have completed 3 or more natural science courses at HWC (Figure 2). According to this figure, students who have taken Natural Science classes only at HWC have the greatest grow when going from 1 -2 to 3+ natural science classes. While those students that took Natural science classes at other colleges grow in knowledge more when moving from 0 classes to 1-2. However, both subpopulations of students, in HWC and other colleges, have similar expert response between 55 and 56%. It can be assumed that the students who comprise the group for 3 or more natural science courses have completed their general education requirement for that area. The results are similar among groups of students who have *only* taken natural science courses at HWC and those who have *only* taken natural science courses at other colleges. Detailed analysis of the groupings' means and standard deviations are provided in Appendix 6.

For each of the EBAPS axes and HWC's SLOs the following percentages were calculated:

Percentage of expert response:	**The percentage for total expert response for each student:**	**The college-wide average percentage of expert response:**
$\frac{\sum \text{all the expert response scores * 100}}{\text{Total \# of statements that belongs to that category.}}$	$\frac{\text{Total of the student's expert responses* 100}}{\text{Total number of statements.}}$	$\frac{\sum \text{the total percentage for expert responses* 100}}{\text{The sample number for the science assessment}}$

Table 4 presents the average percent of expert response in relation to each EBAPS statement within each EBAPS axis. Figure 3 presents bar graphs for the contribution of individual EBAPS statements to each axis. It is noticeable that the higher values reported are between 40 to 60%, whereas lower values, between 20 and 30%, were observed for statements 5 and 15 in axis 1, and 18, 19 and 32 in axis 2. The individual statements in the Science Assessment Tool can be found in Appendix 1.

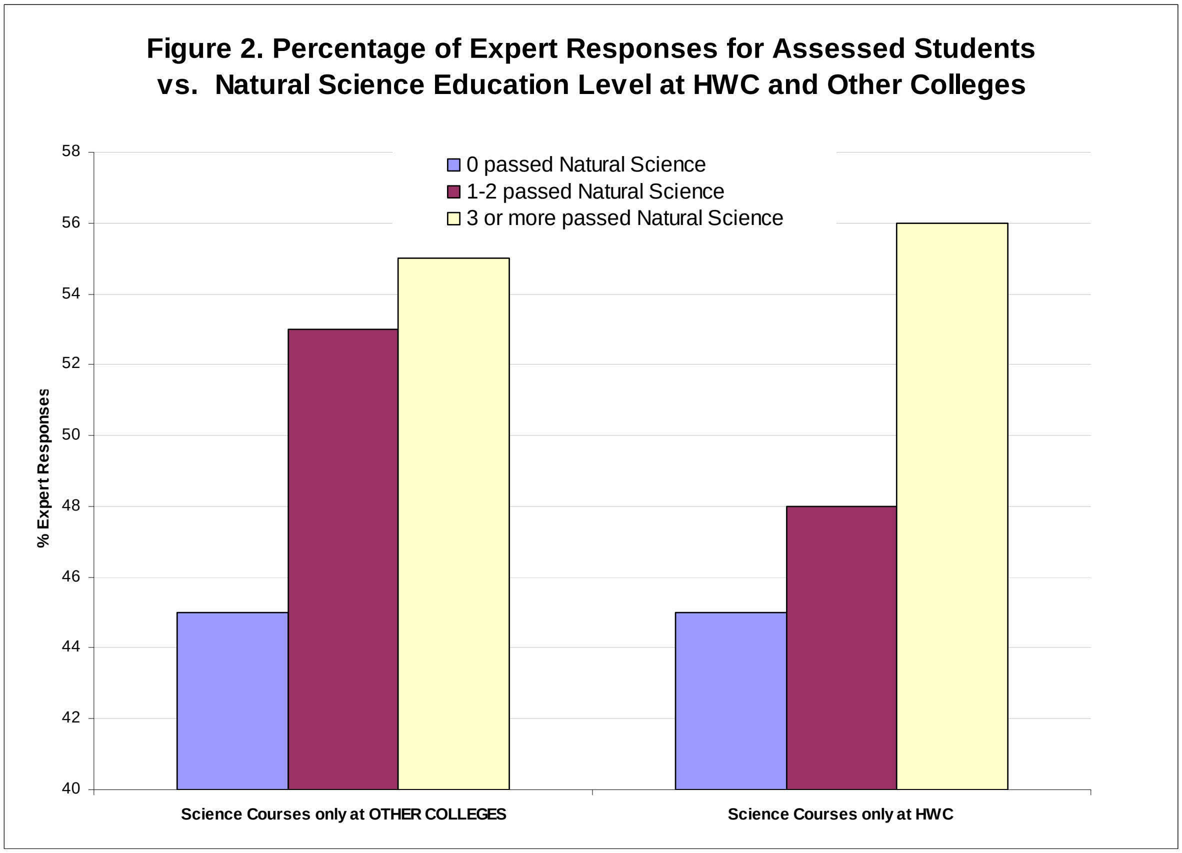
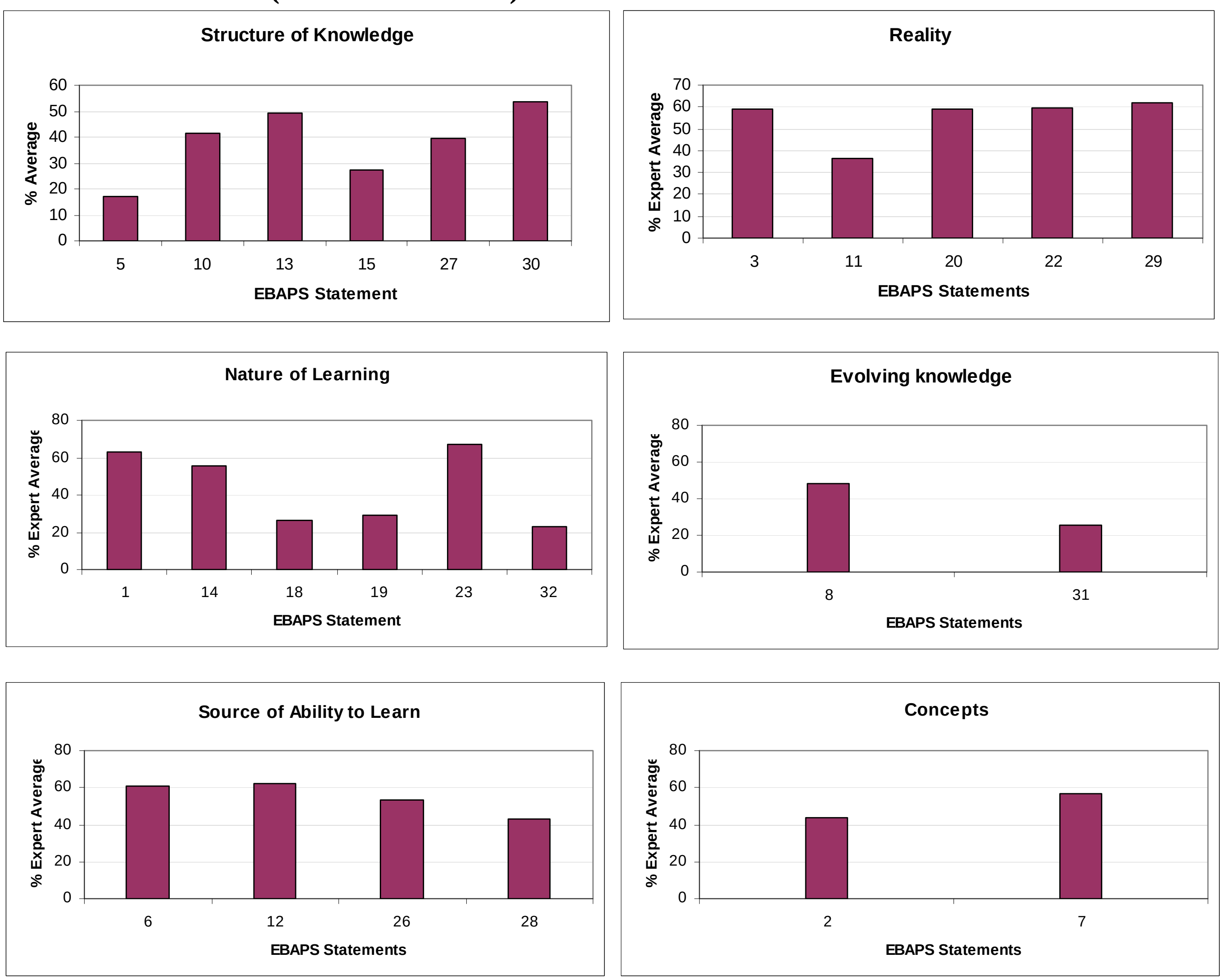


Table 4. Average percent expert response score for each EBAPS statement and its relations with EBAPS axes

EBAPS Axes	EBAPS Statement	% expert average
Structure of Knowledge	5	17
	10	42
	13	49
	15	28
	27	40
	30	54
Nature of Learning	1	63
	14	56
	18	26
	19	29
	23	67
	32	23
Reality	3	59
	11	37
	20	59
	22	60
	29	62

Evolving Knowledge	8	48
	31	25
Source of ability to learn	6	61
	12	62
	26	53
	28	43
Concepts	2	44
	7	56

Figure 3: Average percent expert response score for each EBAPS statement and its relations with EBAPS axes (Data from Table 4)



To facilitate the comparison and spot the differences in performance, the sample of students that participated in the natural science assessment tool at HWC was broken into three sub-populations: 1) students who have taken 0 natural science classes, 2) students who have taken 1 or 2, natural science classes, and 3) students who have taken 3 or more science courses. The analysis of students' performance in relation to the axes defined in EBAPS shows significant improvement as the students' progress in their science education level. The result of expert-level responses of each of the three sub-populations is presented in Table 5.

Table 5. Relationship between the EBAPS Axes with the expert response categorized according to the number of science classes taken at HWC and other institutions

Number of Natural Science Taken at HWC	0	1 to 2	3 or more
Number of Students	402	111	39
"Axes"	**Percentage of Expert Response in Each Subpopulation**		
Structure of Knowledge	37.12	38.01	44.74
Nature of Learning	42.64	45.71	48.22
Real-life applicability	52.82	56.44	68.42
Evolving Knowledge	35.51	37.56	42.76
Source of Ability to Learn	52.93	56.00	65.46
Concepts	48.89	49.42	58.55

Notes: Harmonic means were used to adjust for group size inequalities
Percents are rounded to whole numbers
Bold percents indicate axes that show statistically significant improvement based on completion of science general education requirements; ANOVAs and Tukey statistics were performed

The analysis of these results shows the evolution of students' thinking in relation to the five EBAPS axes as follows:
Structure of Scientific Knowledge: students tend to shift from believing that natural science knowledge consists of memorizing facts, formulas and pieces of information to believing that it is a coherent and structured whole.
Nature of Knowing and Learning: Students' thinking shifts from considering that learning science consists of absorbing information to believing that learning is based on constructing understanding. This understanding is built through learning activities, previous knowledge, intuitions and experiences.
Real-life Applicability: Students move from believing that scientific knowledge applies only in the classroom or laboratory to believing that it applies to their real lives while at the same time developing or increasing their personal interest about natural science.
Evolving knowledge: As their science experience progresses, students understand that science is an evolving process that is enriched with continued advances in knowledge and learning. Also, they become able to differentiate between mere opinions and educated evidence-based interpretation.
Source of Ability to Learn: The increasing trend in the this category shows that students evolve from the attitude that learning and practicing science is a matter of fixed natural ability to believing that effective hard work and good study and practice strategies are critical factors for success in learning and applying science. This evolution in students' thinking and beliefs may have a positive impact in the selection of their major field of study and college retention for those students oriented toward STEM majors.

EBAPS was developed to measure student beliefs about science. In HWC this instrument was adopted to measure SLOs. For this reason, when first picked there was not an obvious alignment between EBAPS statements and HWC's SLOs. The alignment or correspondence between EBAPS statements and HWC's SLOs was established by asking 7 natural science faculties, 5 from the physical science and 2 from the biology departments, to evaluate the pertinence of each EBAPS statement in relation to HWC's

SLOs. Each faculty identified such alignments according to her/his personal beliefs and experience. The statements that correspond to a given SLO were chosen by considering those that were identified by four or more faculty as correlated with the SLO. The results for the SLO versus EBAPS statement alignment is presented in Table 6. Appendix 5 shows the individual faculty and total counts for each SLO.

According to the results in Table 6, two outcomes are specially addressed: SLO1 (Formulate reasonable explanations of natural phenomena based on thorough observations) and SLO4 (Apply steps of the scientific method to solve problems). Statements 6, 9, 12, 15, 16, 28 were not found by any of the participating faculty as aligned with any of the SLO's. However these statements are relevant for the individual axes originally considered in the EBAPS, therefore there are considered equally important.

Table 6: Alignment between EBAPS statements and HWC's SLOs

SLO		**EBAPS Survey Statements**																		**# of statements**
1	Formulate reasonable explanations of natural phenomena based on thorough observations.	2	3	5	7	11	13	14	17	18	19	22	24	29	30	32				**15**
2	Interpret and articulate scientific results that are presented in verbal, graphic and/or tabular form.	4	27																	**2**
3	Critically evaluate scientific resources and scientific claims presented in the media	1	7	8	17	20	22	30												**7**
4	Apply steps of the scientific method to solve problems	2	3	7	10	11	18	19	20	21	22	23	24	25	26	27	29	30	31	**18**

Following the same methodology presented previously for the EBAPS axes a percentage of expert response was determined for the HWC's SLOs. Table 7 presents this average percent of expert response in relation to each EBAPS statement within each of HWC's SLOs. Figure 4 presents bar graphs for the contribution of individual EBAPS statements to each SLO. It is noticeable that the higher values reported are between 40 to 70%, whereas lower values, between 20 and 30%, were again observed for statements 18 and 19 as shown in the graph bar for nature of learning (Axis 2). Appendix 1 shows the statements in the Science Assessment Tool. Table 8 shows the percentage of students that achieved the expert level SLOs response as defined by the statements in Table 7.

To complete the analyses, a modified "normalized learning gain" (**g**) was calculated for each SLO using the results from two of the three subpopulations that were established previously: Students who have taken 0 natural science classes at HWC and students who have taken 3 or more science classes. The normalized learning gain allows the measuring of the impact of science instruction offered at HWC on each specific SLO. According to Hake, 1997), in a pretest-posttest course assessment this value is defined as follows:

Normalized Learning gain (g)=(posttest – pretest)/(100-pretest)

The maximum possible learning gain is 1.00

In the science assessment case, the normalized learning gain was modified with the subpopulation who has not taken science courses considered as analogous to pretest, and the subpopulation of students who have taken 3 or more natural science courses at Harold Washington as analogous to posttest. The normalized learning gain for each SLO may be defined by the expression below and the values are presented in Table 9.

Normalized Learning gain for each SLO (g)=(students who have taken 3 or more natural science courses – students who have not taken science courses)/(100 – students who have not taken science courses)

Normalized Learning gain for each SLO (g) =[(Avg+3 – Avg0)] / [100-(Avg0)].

Table 7. Average percent expert response score for each EBAPS statement and its relations with HWC-SLOs

HWC-NATURAL SCIENCE SLOs	EBAPS Statement	% expert average
SLO 1	2	44
	3	59
	5	17
	7	56
	11	37
	13	49
	14	56
	17	50
	18	26
	19	29
	22	60
	24	48
	29	62
	30	54
	32	23
SLO 2	4	72
	27	40
SLO 3	1	63
	7	56
	8	48
	17	50
	20	59
	22	60
	30	54
SLO 4	2	44
	3	59
	7	56
	10	42
	11	37
	18	26
	19	29
	20	59
	21	65
	22	60
	23	67
	24	48

	25	50
	26	53
	27	40
	29	62
	30	54
	31	25

Figure 4: Average percent expert response score for each EBAPS statement and its relations with HWC's SLOs (Data from Table 7).

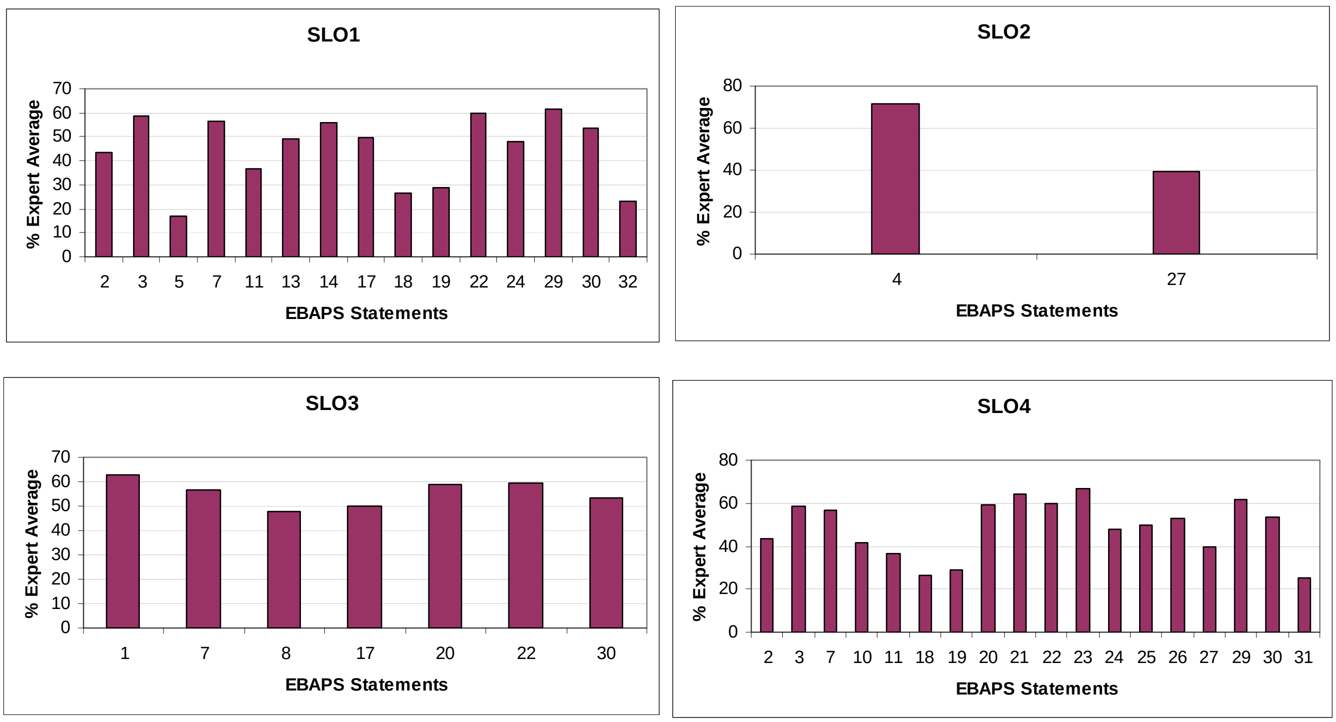


Table 8. Average Percentage of Expert Response for each SLO proposed for the Science Assessment

Average Percentage of Expert Response for each SLO			
SLO 1	**SLO 2**	**SLO 3**	**SLO 4**
Formulate reasonable explanations of natural phenomena based on thorough observations.	Interpret and articulate scientific results that are presented in verbal, graphic and/or tabular form.	Critically evaluate scientific resources and scientific claims presented in the media.	Apply steps of the scientific method to solve problems.
44	**56**	**56**	**48**

Table 9: Normalized Learning Gain (g) for each SLO defined for the HWC Science Assessment.

SLOs	SLO1	SLO2	SLO3	SLO4
Normalized Learning Gain (g)	0. 18	0.08	0.23	0.15

The normalized learning gain is interpreted as a rough measure of the positive impact of the college natural science instruction on students' learning. In general, this gain tends to be low for natural science classes (Hake, 1997). The values reported in Table 9 are considered high results. The best value was obtained for SLO3 with 0.23; for the SLO1 the students have an increase (0.18), similar to SLO4 with 0.15. The lowest value is presented by SLO2 with only 0.08, which could be an artifact due to the number of statements (only 2) that assess this SLO.

When considering the statistic analyses, the null hypothesis (*Ho*) proposed for this assessment assumes that there is no difference in scores for science epistemology *or* SLO subscales between students who have taken no natural science courses at HWC (no college science education), those who have successfully completed 1 to 2 natural science courses at HWC (in progress of completing science general education requirements at HWC), and those who have successfully completed 3 or more natural science courses at HWC (advanced HWC science students).

After performing an inferential test analysis to the data, the null hypothesis could be rejected. This reflects improvements of learning after completing more natural sciences at HWC. The results show statistically significant learning improvements, when students completed more natural science courses at HWC ($p < 0.05$). Student scores became more similar to those of science experts for the EBAPS axes of 1, 2, 3, and 5 when they completed more natural science courses here at HWC (Table 10, Figure 5), and in HWC's SLOs 1, 3, and 4 (Table 11, Figure 6). In these tables, the F test measures the variability of scores of each subpopulation of students and it is used to calculate the p-. The p-value evaluates the significance of the results, when it approaches to zero it means that the results are due to actual differences of the group means and not to random variation (Sullivan, 2010).

A detailed evaluation of tables 10 and 11 and figures 5 and 6 shows that the students' demonstrate significant learning gains in 4 out of the 6 EBAPS axes and in 3 of the 4 HWC- SLOs. Student scores across the three levels of natural science education show improvement for Axis 1 (structure of scientific knowledge), the second axis, nature of knowing and learning, and Axis 5 -Source of Ability to Learn. The most significant improvement is Axis 3 - real-life applicability. Axes 4 and 6 show a trend of improvement that was not supported by a significant level of confidence.

SLO 1, formulate reasonable explanations of natural phenomena based on thorough observations, and SLO3, critically evaluate scientific resources and scientific claims presented in the media, exhibits significant improvement in performance. SLO 4, applying steps of the scientific method to solve problems, exhibited highly significant learning gains. While SLO 2, interpret and articulate scientific results that are presented in verbal, graphic and/or tabular form, is a particularly unique category because it includes only two questions.

This could mean that the students need be re-enforcement in the subjects represent by axes 4 and 6 and SLO 2. These results can also be explained due to the low number of EBAPS statements representing these categories, which is less than those associated to the other axes and SLOs.

These results are also obtained by applying the ad hoc analysis (Tukey's HSD) to the data to establish the rate of improvement (slope) between the subpopulations defined for the sample (Tables 12 and 13). It was found that students who have taken 1-2 natural science classes improve greatly when they take 3+ classes. This rate of improvement is higher than that established between the students that have taken 0 and 1 to 2 for all subscales that show significant differences. Therefore, the aggregated value of learning from taking 3 or more natural science courses seems to be greater than the added value of transitioning from no science to 1-2 courses (Figures 7 and 8). These results also validate the findings presented in Figure 2 that compare and contrast the expert response between students who have taken classes only at HWC with those that have taken the science classes at other colleges.

Table 10. Test for EBAPS Axes

EBPAS Axes		*p*-value Significance
axis1	3.61	0.03
axis2	3.67	0.03
axis3	8.58	0.00
axis4	1.82	0.16
axis5	5.49	0.00
axis6	1.88	0.15

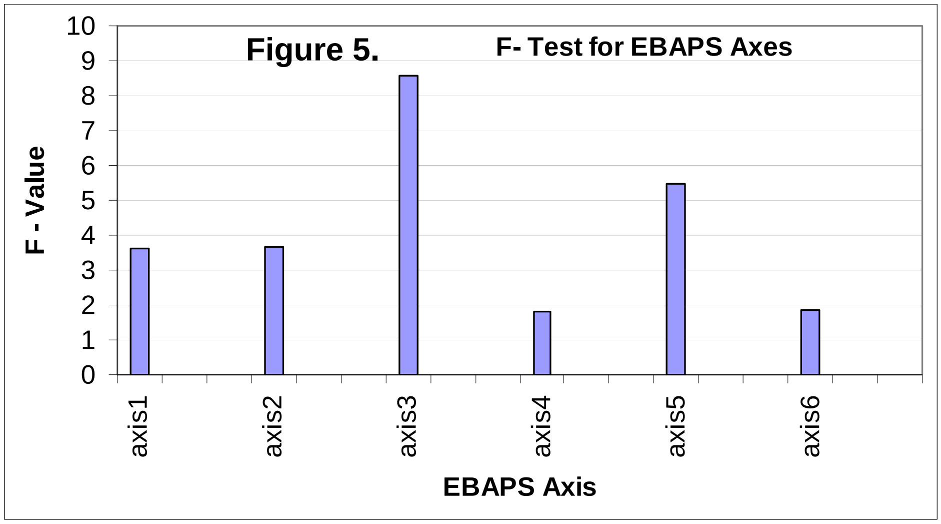


Table 11. Test for SLOs

HWC SLOs		*p*-value Significance
SLO1	9.03	0.00
SLO2	0.34	0.71
SLO3	4.91	0.01
SLO4	6.77	0.00

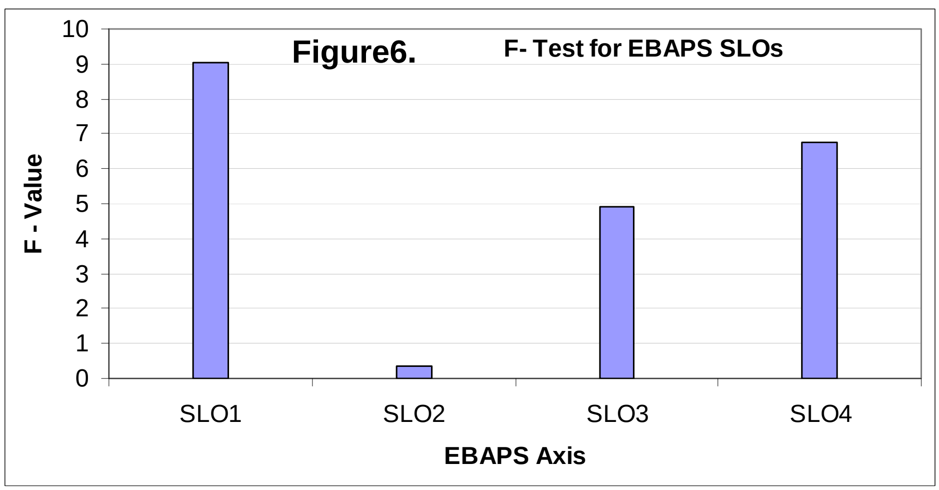
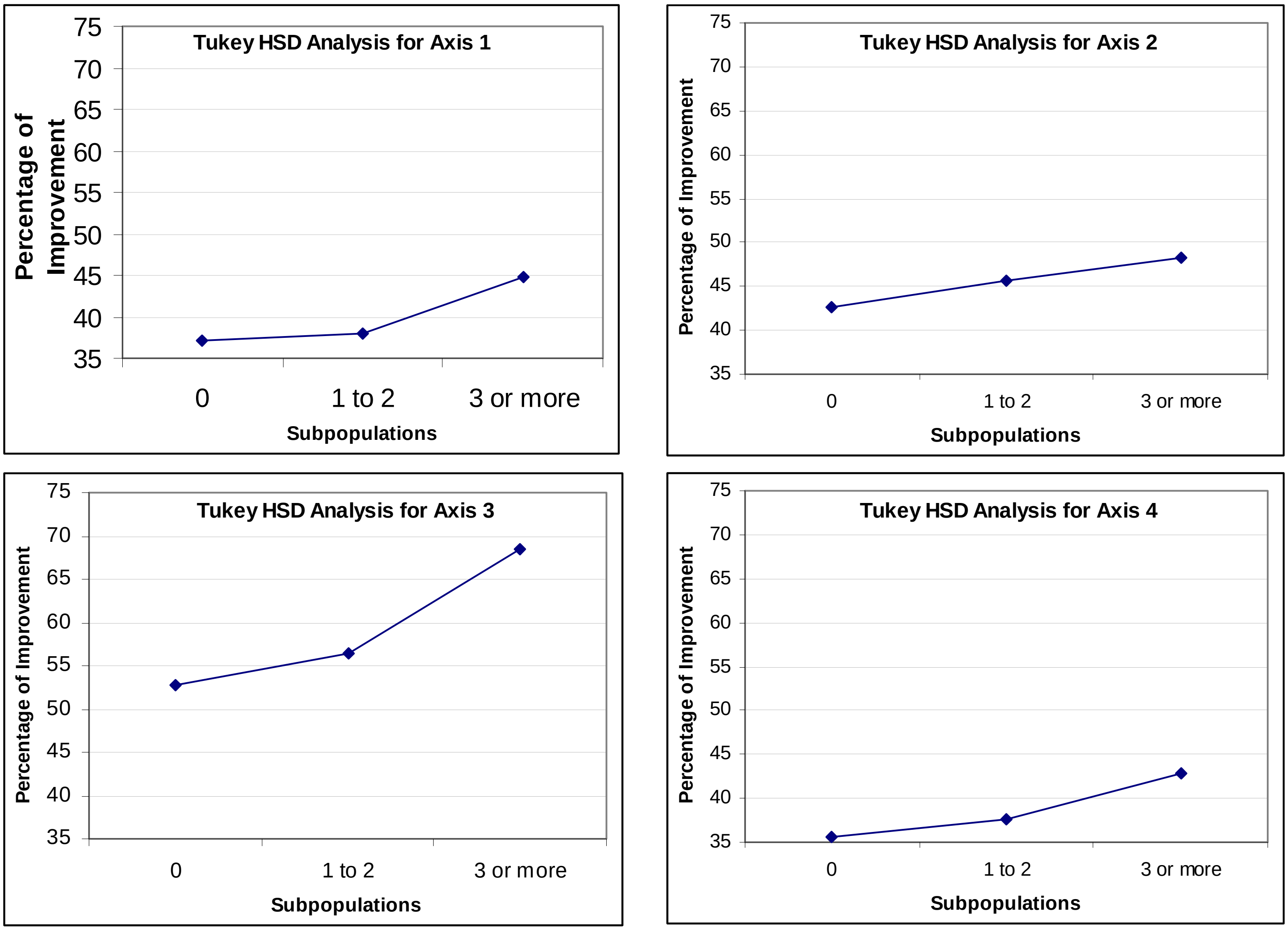


Table 12. Tukey HSD Analysis Results in Percentages for EBAPS Axes

Subpopulations	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5	Axis 6
0	37.12	42.64	52.82	35.51	52.93	48.89
1 to 2	38.01	45.71	56.44	37.56	56.00	49.42
3 or more	44.74	48.22	68.42	42.76	65.46	58.55

Table 13.Tukey HSD Analysis Results in Percentages for HWC's SLOs				
Subpopulations	**SLO1**	**SLO2**	**SLO3**	**SLO4**
0	42.86	55.11	54.21	47.34
1 to 2	45.81	55.47	56.26	48.99
3 or more	53.00	58.55	64.78	55.37

Figure 7. Tukey HSD Analysis Results in Percentages for EBAPS Axes



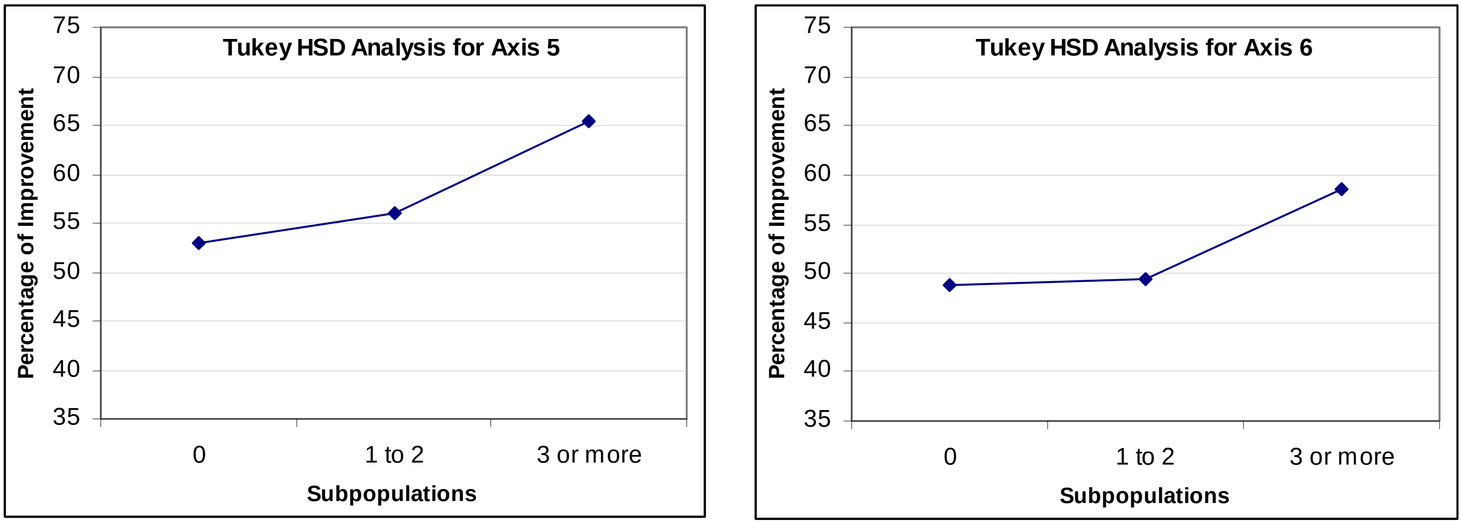
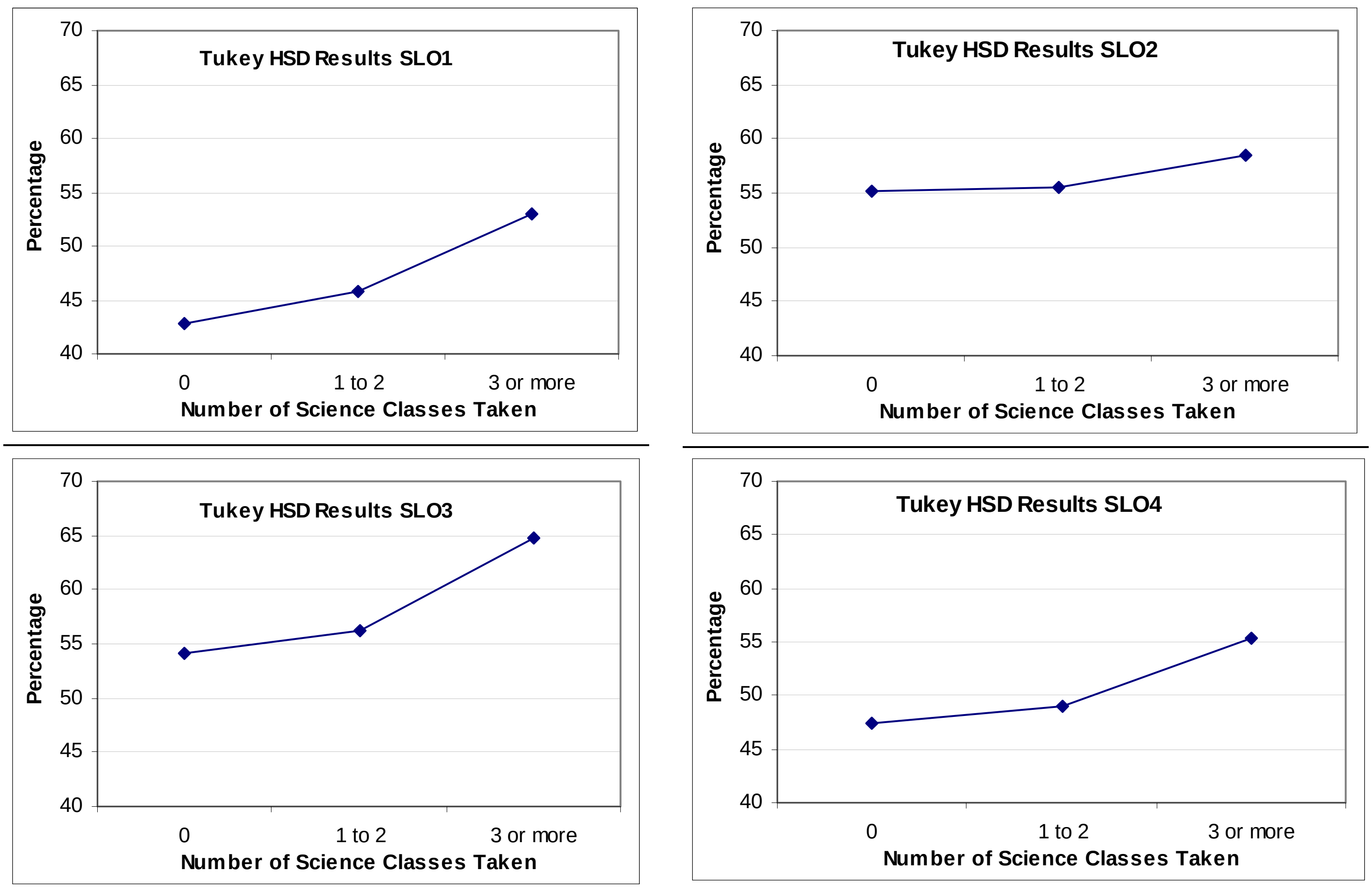


Figure 8.Tukey HSD Analysis Results in Percentages for HWC’s SLOs



V. RELIABILITY AND VALIDITY OF THE NATURAL SCIENCE ASSESSMENT

According to the document: Ideas Behind EBAPS[5] presented in Appendix 4 of this report, the validity and reliability for the EBAPS axes and statements reads as follows:

"Validity testing

Our validity testing focused on this issue. Specifically, after a making two sets of revisions based on pilot subjects and informal feedback, we got about one hundred local community college students to complete our assessment and write down their reasons for responding as they did to each item. We then coded the responses looking for non-epistemological content.
It is instructive to review an item that got invalidated:

- Often, a scientific principle or theory just doesn't make sense. In those cases, you have to accept it and move on.

Several subjects who agreed wrote that, when they first encounter a hard new concept in a fast-paced class, they often "accept and move on," but then go back later and try to make sense of it after they have more background. So, their agreement stems not from epistemological naiveté, but from reasonable survival and learning strategy. The new version of the item may do a better job of getting at students' views about the coherence:

- Often, a scientific principle or theory just doesn't make sense. In those cases, you have to accept it and move on, because not everything in science is supposed to make sense.

This kind of validity testing has the ability to pinpoint issues deserving further study. For instance, in response to our item "When it comes to learning science, memorizing facts is extremely important," some students wrote that it depends on whether they're taking biological or physical science. Apparently, some students hold explicitly discipline-specific stances towards this issue.

What about reliability?

When developing instruments such as EBAPS, researchers often do reliability testing. Specifically, to make sure the items within a given subscale all probe the same beliefs, researchers refine or replace items that do not correlate with the others. We are not using this technique, for a principled reason. We don't want to assume that each subscale corresponds to a stable, consistent belief (or set of beliefs). For instance, consider these two items:

- When learning science, people can understand the material better if they relate it to their own ideas.
- If physics and chemistry teachers gave really clear lectures, with plenty of real-life examples and sample problems, then most good students could learn those subjects without doing lots of sample questions and practice problems on their own.

If both items pass further validity testing, and if students' responses correlate poorly (e.g., if most students agree with both items, even though the favorable response to the second item is disagreement), it's not necessarily because one of the questions is "bad." It might be because students are neither principled constructivists nor principled absorptionists. For this reason, the EBAPS subscales should be viewed as targets for instruction, not as categories of beliefs residing in students' heads.

Indeed, if students' epistemologies consist not of "beliefs" but of more fine-grained cognitive resources whose activation depends on context, then we *expect* students to disagree with themselves, so to speak, about different items in the same subscale. Again, consider the two Nature of Learning items listed above. The question about students' own ideas might trigger the idea that knowledge is something built up (an idea they've abstracted from real-life experiences constructing knowledge), and hence the idea that relating scientific concepts ot their own ideas is productive for learning. The lecture question, by contrast, might trigger the idea that knowledge is "transmitted stuff," and hence, that really clear transmission is sufficient for learning. As discussed in a cognitive theory/practice paper, it's likely that students "have" the idea of knowledge as transmitted stuff *and* the idea of knowledge as built-up stuff; and which idea gets activated in a given moment depends on contextual cues. By allowing students to disagree with themselves within a given subscale — i.e., by not considering this disagreement on its own to indicate "unreliability" in the EBAPS items — we enable EBAPS to probe a range of contexts relevant to learning physical science."

SLO Validity

The alignment between the EBAPS statements and the HWC's SLOs was validated by soliciting science instructors as content experts to align each question to the science SLOs. Each statement-SLO alignment needed to be confirmed by at least 5 of the 7 instructors in order to be considered a valid pairing (for more validity testing information see Appendix 5).

SLO Reliability

Since this is the first time utilizing SLO categories for the EBAPS survey, reliability will evolve as more testing is conducted using this tool to assess the HWC's SLOs. It should also be noted that the assessment committee has a wealth of experience in designing assessment tools to measure SLOs, which enhances the reliability of this particular assessment's question-SLO alignment.

VI. CONCLUSIONS

- The study of the statistical report of the results in aggregate (for 831 students), for each of the 13 questions of the demographic survey and every one of the 32 statements of EBAPS shows the following results:
- 72% of the students reported to be full time. 60% of them are females, 66% are younger than 25 years old. The predominant race is African-American (34%), followed by Hispanic (29%), white (21%), Asian-American (9%), multiracial (4%), while Arabs and Native Americans are less than 1%.

- The data shows a good response and a positive attitude toward science with 74% of the students feeling comfortable with science, 17% indicating that they are "highly comfortable" and 57% are "comfortable". The students also reported high levels of comfort with math (60%), arts (85%), writing (82%) and reading (91%). Similarly, ~50% agreed to some degree that the study of science has useful applications to their every-day lives, helps them to become more rational and logical, gives them important skills that they can use in other classes, and influences them to read science books. 14% recognized that taking science classes has helped them achieve their goals, 18% thought that they have broadened their scientific interests, and ~10 to 15% recognize science's connection with religion, society and politics.

- The students' behavior towards science is very positive. Compared to the time before the surveyed students came to HWC, 52% agree that they are more likely to read different types of books; 40% agree that they are more likely to read scientific articles; 56% agree that they are more likely to discuss life's big questions; 57% feel confident about understanding what they read, see, and hear. 12% visited the Museum of Science and Industry, Planetarium, Aquarium, or the Field Museum; 40% attend a film presentation of a science-related documentary; 8% went a science-related event; 10% go to a science-related lecture or educational presentation; 9% debate on a scientific subject (i.e. climate change). However, only 30% would have taken science classes even if they were not required. These results show a disconnection between the level of comfort and the attitude towards science and their cognitive skills.

- According to the analyses applied to 3 defined subpopulation, the students' performance in natural science shows significant improvement as the students progress in their science education level. In overall, students' performance changed from an overall mean score of 47% among students who have taken 0 natural science courses to 55% among students who have completed 3 or more natural science courses at HWC.

- A detailed evaluation of the results shows that the students' demonstrate significant learning gains in 4 out of the 6 EBAPS axes and in 3 of the 4 HWC- SLOs. Student scores across the three levels of natural science education show improvement for Axis 1 (structure of scientific knowledge), the second axis, nature of knowing and learning, and Axis 5 -Source of Ability to Learn. The most significant improvement is Axis 3 - real-life applicability. Axes 4 and 6 show a trend of improvement that was not supported by a significant level of confidence.

- SLO 1, formulate reasonable explanations of natural phenomena based on thorough observations, and SLO3, critically evaluate scientific resources and scientific claims presented in the media, exhibits significant improvement in performance. SLO 4, applying steps of the scientific method to solve problems, exhibited highly significant learning gains. While SLO 2, interpret and articulate scientific results that are presented in verbal, graphic and/or tabular form, is a particularly unique category because it includes only two questions. These results can signify that the students need re-enforcement in these features represent by axes 4 and 6 and SLO 2 or can also be explained due that the number of EBAPS statements that assess each of these categories, they are less than those associated to the other axes and SLOs.

- Students who have taken Natural Science classes only at HWC have the greatest grow when going from 1 -2 to 3+ natural science classes. While those students that took Natural science classes at other colleges grow in knowledge more when moving from 0 classes to 1-2. However, both subpopulations of students, in HWC and other colleges, have similar expert response between 55 and 56%. It can be assumed that the students who comprise the group for 3 or more natural science courses have completed their general education requirement for that area. The results are similar among groups of students who have *only* taken natural science courses at HWC and those who have *only* taken natural science courses at other colleges.

- The analysis of the data shows similar learning gain trends among students who have taken courses at HWC regardless of how many natural science courses were taken at other colleges, in comparison to who have taken natural science courses only at other colleges and those that have taken courses only at HWC.

- **VII. RECOMMENDATIONS**

- The EBAPS focuses on epistemological beliefs of students about knowing and learning science, while HWC's SLOs focus on how the students apply science knowledge in everyday situations. For this reason we consider EBAPS to be an indirect assessment tool of HWC's SLOs. We propose to enrich the general science assessment survey by adding direct assessment questions for each SLO, especially to reinforce SLO 2.

- Scoring of "non-expert" or "unfavorable" and "neutral" should be addressed both individually and for the college average.

- In the tool there is not a statement intended to catch students who are not reading the survey, who just mark answers without reading the questions. A statement should be added for this purpose. Adams et al., 2005 recommend the following: "We use this question to discard the survey of people who are not reading the statements. Please select "agree"—option 4 (not "strongly agree") to preserve your answers"

- Prior scientific education: is there a fairly consistent/statistically significant difference between responses from students who have taken science courses at HWC vs other colleges that is largely independent from other factors?

- Freshman vs Senior: is there a fairly consistent/statistically significant difference between responses from "freshman" vs "senior" level students that is largely independent from other factors?

- Student age: is there a fairly consistent difference/statistically significant difference between responses from different group-age students that is largely independent from other factors? (18-21 vs 30-33 years-old?).

- Student gender: is there a fairly consistent difference/statistically significant difference between responses from different gender students that is largely independent from other factors?

- To reinforce the validity of the survey, it is necessary to take into account whether or not the students answer according to their beliefs or to what they think is the "correct answer" expected from them.

- After the analysis for axes and SLOs, it is clear that the low expert-level performance of students for statement 18 suggests that students believe that formulas or equations are the main thing to understand in science. Regarding statement 19, students consider that the work of the instructor is paramount in their own efforts to learn science. To change these beliefs, the instructors could emphasize conceptual learning and engage students using active learning activities.

- Students' scores are more expert-like for the EBAPS axes of 1, 2, 3, and 5; and SLOs 1, 3, and 4 as they progress in their natural science courses at HWC. However, the students' performance for Axis 4 (**Evolving Knowledge**) and Axis 6 (**Concepts**) and SLO2 **(interpret and articulate scientific results that are presented in verbal, graphic and/or tabular form)** show a trend of improvement that was not very significant. These results invite to re-enforce the subjects represent by these axes and this SLO.

- It is recommended to perform test-retest reliability studies of the survey over large populations and over a few-semester difference, to decrease the effect of change in student population.

- Changes should be introduced in instructional and curricular design to help HWC's students develop more sophisticated beliefs about learning and science.

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IX. APPENDIXES

Appendix 1
HWC the Natural Science Assessment Tool
Demographic Survey and Integrated General Science Version EBAPS

Harold Washington College Science Assessment
Fall 2008

SCIENCE DEMOGRAPHICS

The following demographic questions will be used to determine whether the sample of students who take this assessment are a representative sample of the student body at large in order to check the reliability of the data obtained.

Please fill in marks like this: ● **not like this:** ⦸ ⊗

1. Please indicate the total number of college level credit hours that you have passed (grade C or better):
   At HWC: O 0 O 1-15 O 16-30 O 31+

2. Please indicate the total number of college level credit hours that you have passed (grade C or better):
   At other colleges: O 0 O 1-15 O 16-30 O 31+

3. At HWC we define **the Natural Sciences** as the life sciences (Biology, Zoology, and Botany) and the physical sciences (Physics, Chemistry, and Earth Sciences - Geology, Meteorology Oceanography and Astronomy). Given that definition, please indicate how many courses you have successfully completed in **the Natural Sciences:**
   At HWC: O 0 O 1-2 O 3+

4. Given that definition, please indicate how many courses you have successfully completed in **the Natural Sciences:**
   At other colleges: O 0 O 1-2 O 3+

5. Please indicate your sex:
   O Female
   O Male

6. Please indicate your race and/or ethnicity:
   O African American/Black O Arab/Arab American O Asian American/Pacific Islander
   O Hispanic/Latino/Chicano O Multi-racial/Multi-Ethnic O Native American/Alaska Native
   O White/Caucasian

7. Please indicate your age:
   O 25 or under O 41-60
   O 26-40 O 61+

8. Please indicate your current academic status:
   O Full time (enrolled 12 credit hours or more)
   O Part time (enrolled less than 12 credit hours)

The following questions will ask you about your interests, values, and opinions related to the Natural Sciences (**the life sciences: Biology, Zoology, and Botany*****). Use this time to think honestly about yourself.***

	9. Please indicate your comfort level with:	**Highly Comfortable**	**Comfortable**	**Uncomfortable**	**Highly Uncomfortable**
a.	science	Ⓐ	Ⓑ	Ⓒ	Ⓓ
b.	math	Ⓐ	Ⓑ	Ⓒ	Ⓓ
c.	writing	Ⓐ	Ⓑ	Ⓒ	Ⓓ
d.	reading	Ⓐ	Ⓑ	Ⓒ	Ⓓ
e.	arts	Ⓐ	Ⓑ	Ⓒ	Ⓓ

	10. I think studying the natural sciences:	**Strongly disagree**	**Somewhat disagree**	**Neutral**	**Somewhat agree**	**Strongly agree**
a.	has given me new ways to think about my own life	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
b.	has given me important skills to use in other classes	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
c.	has <u>not</u> helped me reach my academic and/or personal goals	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
d.	has helped me become a more rational/logical person	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
e.	has <u>not</u> helped broaden my interest in scientific topics	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
f.	is something I would have done even if there were not a science requirement	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ

11. Compared to the time before I came to HWC, I am now more likely to:		Strongly disagree	Somewhat disagree	Neutral	Somewhat agree	Strongly agree
a.	read different types of books	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
b.	enjoy different types of science shows (i.e. Discovery Channel)	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
c.	read scientific articles in newspaper or magazines	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
d.	relate science to race or ethnicity	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
e.	relate science to sex or gender	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
f.	relate science to sexuality	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
g.	relate science to religion	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
h.	relate science to society	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
i.	relate science to politics	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
j.	discuss life's big questions	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ

12. Compared to the time before I came to HWC, I am now more likely to:						
a.	search for meaning in books and articles I read	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
b.	attend a science event	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
c.	visit a museum or research laboratory	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
d.	bring family, friends, or coworkers to a science event	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
e.	feel confident about understanding what I read, see, and hear	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
f.	feel confident about interpreting scientific works	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
g.	feel confident about what I write	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
h.	feel confident about what I say in class	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
i.	find value in scientific works even if I don't understand them	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ

13. Since coming to HWC, have you attended or otherwise experienced (indicate all that apply):		Yes, and it was a new experience	Yes, but it was not new to me	No, but I have experienced this before	No, and I have never experienced this
a.	the Museum of Science and Industry, Planetarium, Aquarium, or the Field Museum of Natural History	Ⓐ	Ⓑ	Ⓒ	Ⓓ
b.	a science-related special event (i.e. Body Works or Science in the City)	Ⓐ	Ⓑ	Ⓒ	Ⓓ
c.	a film presentation of a science-related documentary	Ⓐ	Ⓑ	Ⓒ	Ⓓ
d.	a science-related lecture or educational presentation (non-credit)	Ⓐ	Ⓑ	Ⓒ	Ⓓ
e.	a debate on a scientific topic (i.e. climate change).	Ⓐ	Ⓑ	Ⓒ	Ⓓ

Epistemological Beliefs Assessment for Physical Science (EBAPS)

Part 1

<u>DIRECTIONS</u>: *For each of the following items, please read the statement, and fill in the circle that describes how strongly you agree or disagree.*

A: Strongly disagree B: Somewhat disagree C: Neutral D: Somewhat agree E: Strongly agree

		Strongly disagree	Somewhat disagree	Neutral	Somewhat agree	Strongly agree
1	Tamara just read something in her science textbook that seems to disagree with her own experiences. But to learn science well, Tamara shouldn't think about her own experiences; she should just focus on what the book says	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
2	"Problem solving" in most science courses basically means matching problems with facts or equations and then substituting values to get a number	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
3	Learning science made me change some of my ideas about how scientific phenomena can be used to understand the world around me	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
4	If someone is having trouble in science class, studying in a better way can make a big difference	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
5	Knowledge in science consists of many pieces of information, each of which applies primarily to a specific situation	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
6	Only very few specially qualified people are capable of really understanding the sciences	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
7	"Understanding" science basically means being able to recall something you've read or been shown	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
8	When it comes to controversial topics such as which foods cause cancer, there's no way for scientists to evaluate which scientific studies are the best	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
9	A teacher once said, "I don't *really* understand something until I teach it." But actually, teaching doesn't help individuals understand the material better; it just reminds them of how much they already know	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
10	My grade in science classes will be primarily determined by how familiar I am with the material. Insight or creativity will have little to do with it	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ

		A	B	C	D	E
11	Science phenomena are related to the real world and it sometimes helps to think about the connection, but it is rarely essential for what I will probably be doing in my career..........	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
12	Someone who doesn't have high natural ability can still learn the material well even in a science class..........	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
13	Often, a scientific principle or theory just doesn't make sense. In those cases, you have to accept it and move on, because not everything in science is supposed to make sense..........	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
14	When learning science, people can understand the material better if they relate it to their own ideas..........	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
15	A significant problem in science classes will probably be memorizing all the information I need to know..........	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
16	When it comes to science, most students either learn things quickly or not at all..........	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
17	The main skill I expect to get out of science classes is to learn how to reason logically about the physical world..........	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
18	To understand science, the formulas (equations) are really the main thing; the other material is mostly to help you decide which equations to use in which situations..........	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
19	If science teachers gave *really clear* lectures, with plenty of real-life examples and sample problems, then most good students could learn those subjects without doing lots of sample questions and practice problems on their own..........	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
20	Understanding science is really important for people who design rockets, but not important for politicians..........	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
21	Given enough time, almost everybody could learn to think more scientifically, if they really wanted to..........	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ
22	Learning science will help me understand situations in my everyday life..........	Ⓐ	Ⓑ	Ⓒ	Ⓓ	Ⓔ

Part 2

DIRECTIONS: *Multiple choice. Fill in the circle that best fits your view.*

23. Some people have 'photographic memory', the ability to recall essentially everything they read. To what extent would photographic memory give you an advantage when learning science?

Ⓐ It would be the most helpful thing that could happen to me

Ⓑ It would help a lot.

Ⓒ It would help a fair amount.

Ⓓ It would help a little.

Ⓔ It would hardly help at all.

24. Scientists are having trouble predicting and explaining the behavior of thunderstorms. This could be because thunderstorms behave according to a very complicated set of rules. Or, that could be because some thunderstorms don't behave consistently according to *any* set of rules, no matter how complicated and complete that set of rules is.

In general, why do scientists sometimes have trouble explaining things? Please read all options before choosing one.

Ⓐ The system simply doesn't obey definable rules.

Ⓑ Most of the time it's because the system doesn't obey definable rules; but sometimes it's because the system follows rules that are very complex or difficult to figure out.

Ⓒ About half the time it's because the system doesn't obey rules, and the other half it's because the rules are complex or difficult to figure out.

Ⓓ Most of the time it's because rules are complex or difficult to figure out, but sometimes it's because the system doesn't follow definable rules.

Ⓔ A natural system always follows definable rules but the rules can be very complex or difficult to figure out.

25. To be successful at *most things in life...*

Ⓐ Hard work is much more important than inborn natural ability.

Ⓑ Hard work is a little more important than natural ability.

Ⓒ Natural ability and hard work are equally important.

Ⓓ Natural ability is a little more important than hard work.

Ⓔ Natural ability is much more important than hard work.

26. To be successful at *science...*

Ⓐ Hard work is much more important than inborn natural ability.

Ⓑ Hard work is a little more important than natural ability.

Ⓒ Natural ability and hard work are equally important.

Ⓓ Natural ability is a little more important than hard work.

Ⓔ Natural ability is much more important than hard work.

27. Of the following test formats, which is best for measuring how well you understand the material in one of the science classes? Please read each choice before picking one.

Ⓐ A large collection of short-answer or multiple choice questions, covering one specific fact or concept.

Ⓑ A small number of longer questions and problems, covering several facts and concepts.

Ⓒ Compromise between (a) and (b), but leaning more towards (a).

Ⓓ Compromise between (a) and (b), favoring both equally.

Ⓔ Compromise between (a) and (b), but leaning more towards (b).

Part 3

DIRECTIONS: *In each of the following items, you will read a short discussion between two students who disagree about some issue. Then you'll indicate whether you agree with one student or the other*

28.

Anna: I just read about Kay Kinoshita, the physicist. She sounds naturally brilliant.

Emily: Maybe she is. But when it comes to being good at science, hard work is more important than "natural ability." I bet Dr. Kinoshita does well because she has worked really hard.

Anna: Well, maybe she did. But let's face it; some people are just smarter at science than other people. Without natural ability, hard work won't get you anywhere in science!

Ⓐ I agree almost entirely with Anna.
Ⓑ Although I agree more with Anna, I think Emily makes some good points.
Ⓒ I agree (or disagree) equally with Anna and Emily.
Ⓓ Although I agree more with Emily, I think Anna makes some good points.
Ⓔ I agree almost entirely with Emily.

29.

Julia: I like the way science explains the things I see in the real world.

Carla: I know that's what we're "supposed" to think, and it's true for many things. But let's face it, the science that explains things we do in lab at school can't really explain earthquakes, for instance. Scientific laws work well in some situations but not in most situations.

Julia: I still think science applies to almost all real-world experiences. If we can't figure out how, it's because the stuff is very complicated, or because we don't know enough science yet.

Ⓐ I agree almost entirely with Julia.
Ⓑ I agree more with Julia, but I think Carla makes some good points.
Ⓒ I agree (or disagree) equally with Carla and Julia.
Ⓓ I agree more with Carla, but I think Julia makes some good points.
Ⓔ I agree almost entirely with Carla.

30.

Leticia: Some scientists think the dinosaurs died out because of volcanic eruptions, and others think they died out because an asteroid hit the Earth. Why can't the scientists agree?

Nisha: Maybe the evidence supports both theories. There's often more than one way to interpret the facts. So we have to figure out what the facts mean.

Leticia: I'm not so sure. In stuff like personal relationships or poetry, things can be ambiguous. But in science, the facts speak for themselves.

Ⓐ I agree almost entirely with Leticia.
Ⓑ I agree more with Leticia, but I think Nisha makes some good points.
Ⓒ I agree (or disagree) equally with Nisha and Leticia.
Ⓓ I agree more with Nisha, but I think Leticia makes some good points.
Ⓔ I agree almost entirely with Nisha.

31.

Jose: In my opinion, science is a little like fashion; something that's "in" one year can be "out" the next. Scientists regularly change their theories back and forth.

Miguel: I have a different opinion. Once experiments have been done and a theory has been made to explain those experiments, the matter is pretty much settled. There's little room for argument.

Ⓐ I agree almost entirely with Jose.
Ⓑ Although I agree more with Jose, I think Miguel makes some good points.
Ⓒ I agree (or disagree) equally with Miguel and Jose.
Ⓓ Although I agree more with Miguel, I think Jose makes some good points.
Ⓔ I agree almost entirely with Miguel.

32.

Jessica and Mia are talking about their experiences in their group.

Jessica: "I feel like explaining something to other people in my group really helps me understand it better."

Mia: "I don't think explaining helps you understand better. It's just that when you can explain something to someone else, then you know you really understand it."

Ⓐ I agree almost entirely with Jessica.
Ⓑ I agree more with Jessica, but I think Mia makes some good points.
Ⓒ I agree (or disagree) equally with Mia and Jessica.
Ⓓ I agree more with Mia, but I think Jessica makes some good points.
Ⓔ I agree almost entirely with Mia.

Appendix 2
Science Assessment Item Analysis Report, Fall 08
Office of Research and Planning

Science Assessment Item Analysis - Fall, 2008

of college level credit hours that passed at HWC

Response	Frequency	Percent
0	177	21.30
1-15	278	33.45
16-30	201	24.19
31+	165	19.86
Missing	10	1.20

Mean: 2.43

Natural Science courses passed at HWC

Response	Frequency	Percent
0	520	62.58
1-2	225	27.08
3+	76	9.15
Missing	10	1.20

Mean: 1.46

of college level credit hours passed at other colleges

Response	Frequency	Percent
0	315	37.91
1-15	191	22.98
16-30	119	14.32
31+	186	22.38
Missing	20	2.41

Mean: 2.22

Natural Science courses passed at other colleges

Response	Frequency	Percent
0	548	65.94
1-2	194	23.35
3+	78	9.39
Missing	11	1.32

Mean: 1.43

sex

Response	Frequency	Percent
female	493	59.33
male	337	40.55
Missing	1	0.12

Mean: 1.41

ethnicity

Response	Frequency	Percent
african american	276	33.21
arab	7	0.84
asian american	77	9.27
hispanic	240	28.88
multi-racial	35	4.21
native american	4	0.48
white	178	21.42
Missing	14	1.68

Mean: 3.58

age

Response	Frequency	Percent
25 or under	550	66.19
26-40	223	26.84
41-60	53	6.38
61+	2	0.24
Missing	3	0.36

Mean: 1.40

academic status

Response	Frequency	Percent
Full time	600	72.20
Part time	227	27.32
Missing	4	0.48

Mean: 1.27

science

Response	Frequency	Percent
highly comfortable	142	17.09
comfortable	473	56.92
uncomfortable	166	19.98
highly uncomfortable	45	5.42
Missing	5	0.60

Mean: 2.14

math

Response	Frequency	Percent
highly comfortable	168	20.22
comfortable	338	40.67
uncomfortable	213	25.63
highly uncomfortable	110	13.24
Missing	2	0.24

Mean: 2.32

writing

Response	Frequency	Percent	Mean: 1.84
highly comfortable	294	35.38	
comfortable	396	47.65	
uncomfortable	112	13.48	
highly uncomfortable	26	3.13	
Missing	3	0.36	

arts

Response	Frequency	Percent	Mean: 1.80
highly comfortable	313	37.67	
comfortable	393	47.29	
uncomfortable	90	10.83	
highly uncomfortable	29	3.49	
Missing	6	0.72	

has given me important skills to use in other classes

Response	Frequency	Percent	Mean: 2.77
Strongly Disagree	0	0.00	
Somewhat Disagree	46	5.54	
Neutral	228	27.44	
Somewhat Agree	255	30.69	
Strongly Agree	162	19.49	
Missing	140	16.85	

has helped me become more rational/logical

Response	Frequency	Percent	Mean: 2.72
Strongly Disagree	0	0.00	
Somewhat Disagree	49	5.90	
Neutral	247	29.72	
Somewhat Agree	224	26.96	
Strongly Agree	157	18.89	
Missing	154	18.53	

is something I would have done even if there was not a req

Response	Frequency	Percent	Mean: 2.51
Strongly Disagree	0	0.00	
Somewhat Disagree	95	11.43	
Neutral	243	29.24	
Somewhat Agree	139	16.73	
Strongly Agree	132	15.88	
Missing	222	26.71	

reading

Response	Frequency	Percent	Mean: 1.63
highly comfortable	391	47.05	
comfortable	362	43.56	
uncomfortable	62	7.46	
highly uncomfortable	13	1.56	
Missing	3	0.36	

has given me new ways to think about my own life

Response	Frequency	Percent	Mean: 2.81
Strongly Disagree	0	0.00	
Somewhat Disagree	36	4.33	
Neutral	248	29.84	
Somewhat Agree	228	27.44	
Strongly Agree	188	22.62	
Missing	131	15.76	

has not helped me reach my goals

Response	Frequency	Percent	Mean: 1.97
Strongly Disagree	0	0.00	
Somewhat Disagree	172	20.70	
Neutral	205	24.67	
Somewhat Agree	75	9.03	
Strongly Agree	40	4.81	
Missing	339	40.79	

has not helped broaden my interest in scientific subjects

Response	Frequency	Percent	Mean: 2.05
Strongly Disagree	0	0.00	
Somewhat Disagree	176	21.18	
Neutral	200	24.07	
Somewhat Agree	86	10.35	
Strongly Agree	57	6.86	
Missing	312	37.55	

read different types of books

Response	Frequency	Percent	Mean: 2.70
Strongly Disagree	0	0.00	
Somewhat Disagree	86	10.35	
Neutral	250	30.08	
Somewhat Agree	255	30.69	
Strongly Agree	186	22.38	
Missing	54	6.50	

enjoy different types of science shows

Response	Frequency	Percent	Mean: 2.63
Strongly Disagree	0	0.00	
Somewhat Disagree	90	10.83	
Neutral	277	33.33	
Somewhat Agree	232	27.92	
Strongly Agree	173	20.82	
Missing	59	7.10	

read scientific articles

Response	Frequency	Percent	Mean: 2.41
Strongly Disagree	0	0.00	
Somewhat Disagree	125	15.04	
Neutral	298	35.86	
Somewhat Agree	224	26.96	
Strongly Agree	103	12.39	
Missing	81	9.75	

relate science to race

Response	Frequency	Percent	Mean: 2.36
Strongly Disagree	0	0.00	
Somewhat Disagree	124	14.92	
Neutral	321	38.63	
Somewhat Agree	203	24.43	
Strongly Agree	96	11.55	
Missing	87	10.47	

relate science to sex

Response	Frequency	Percent	Mean: 2.46
Strongly Disagree	0	0.00	
Somewhat Disagree	108	13.00	
Neutral	304	36.58	
Somewhat Agree	212	25.51	
Strongly Agree	118	14.20	
Missing	89	10.71	

relate science to sexuality

Response	Frequency	Percent	Mean: 2.40
Strongly Disagree	0	0.00	
Somewhat Disagree	111	13.36	
Neutral	324	38.99	
Somewhat Agree	193	23.23	
Strongly Agree	107	12.88	
Missing	96	11.55	

relate science to religion

Response	Frequency	Percent	Mean: 2.29
Strongly Disagree	0	0.00	
Somewhat Disagree	128	15.40	
Neutral	316	38.03	
Somewhat Agree	159	19.13	
Strongly Agree	84	10.11	
Missing	144	17.33	

relate science to society

Response	Frequency	Percent	Mean: 2.60
Strongly Disagree	0	0.00	
Somewhat Disagree	83	9.99	
Neutral	285	34.30	
Somewhat Agree	261	31.41	
Strongly Agree	140	16.85	
Missing	62	7.46	

relate science to politics

Response	Frequency	Percent	Mean: 2.34
Strongly Disagree	0	0.00	
Somewhat Disagree	112	13.48	
Neutral	354	42.60	
Somewhat Agree	179	21.54	
Strongly Agree	91	10.95	
Missing	95	11.43	

discuss lifes big questions

Response	Frequency	Percent	Mean: 2.71
Strongly Disagree	0	0.00	
Somewhat Disagree	77	9.27	
Neutral	258	31.05	
Somewhat Agree	235	28.28	
Strongly Agree	194	23.35	
Missing	67	8.06	

search for meaning in books and articles

Response	Frequency	Percent	Mean: 2.69
Strongly Disagree	0	0.00	
Somewhat Disagree	77	9.27	
Neutral	261	31.41	
Somewhat Agree	264	31.77	
Strongly Agree	173	20.82	
Missing	56	6.74	

attend a science event

Response	Frequency	Percent	Mean: 2.23
Strongly Disagree	0	0.00	
Somewhat Disagree	153	18.41	
Neutral	324	38.99	
Somewhat Agree	182	21.90	
Strongly Agree	71	8.54	
Missing	101	12.15	

visit museum or research lab

Response	Frequency	Percent	Mean: 2.58
Strongly Disagree	0	0.00	
Somewhat Disagree	102	12.27	
Neutral	281	33.81	
Somewhat Agree	232	27.92	
Strongly Agree	157	18.89	
Missing	59	7.10	

bring people to a science event

Response	Frequency	Percent	Mean: 2.23
Strongly Disagree	0	0.00	
Somewhat Disagree	136	16.37	
Neutral	352	42.36	
Somewhat Agree	159	19.13	
Strongly Agree	73	8.78	
Missing	111	13.36	

feel confident about understanding what I read see and hear

Response	Frequency	Percent	Mean: 2.75
Strongly Disagree	0	0.00	
Somewhat Disagree	64	7.70	
Neutral	243	29.24	
Somewhat Agree	302	36.34	
Strongly Agree	175	21.06	
Missing	47	5.66	

feel confident about interpreting scientific works

Response	Frequency	Percent	Mean: 2.50
Strongly Disagree	0	0.00	
Somewhat Disagree	93	11.19	
Neutral	310	37.30	
Somewhat Agree	255	30.69	
Strongly Agree	111	13.36	
Missing	62	7.46	

feel confident about what I write

Response	Frequency	Percent	Mean: 2.71
Strongly Disagree	0	0.00	
Somewhat Disagree	65	7.82	
Neutral	264	31.77	
Somewhat Agree	283	34.06	
Strongly Agree	170	20.46	
Missing	49	5.90	

feel confident about what I say in class

Response	Frequency	Percent	Mean: 2.72
Strongly Disagree	0	0.00	
Somewhat Disagree	68	8.18	
Neutral	261	31.41	
Somewhat Agree	288	34.66	
Strongly Agree	173	20.82	
Missing	41	4.93	

find value in scientific works even if I dont understand

Response	Frequency	Percent	Mean: 2.61
Strongly Disagree	0	0.00	
Somewhat Disagree	67	8.06	
Neutral	320	38.51	
Somewhat Agree	235	28.28	
Strongly Agree	150	18.05	
Missing	59	7.10	

the Museum of S and I or the Field Museum

Response	Frequency	Percent	Mean: 2.48
Yes and it was a new experience	99	11.91	
Yes but it wasn't new to me	304	36.58	
No but I have experienced this before	355	42.72	
No and I have never experienced this	69	8.30	
Missing	4	0.48	

a science related event

Response	Frequency	Percent	Mean: 3.04
Yes and it was a new experience	69	8.30	
Yes but it wasn't new to me	152	18.29	
No but I have experienced this before	283	34.06	
No and I have never experienced this	320	38.51	
Missing	7	0.84	

a film presentation of a science based documentary

Response	Frequency	Percent	Mean: 2.74
Yes and it was a new experience	104	12.52	
Yes but it wasn't new to me	223	26.84	
No but I have experienced this before	277	33.33	
No and I have never experienced this	220	26.47	
Missing	7	0.84	

a science related lecture or educational presentation

Response	Frequency	Percent	Mean: 3.04
Yes and it was a new experience	80	9.63	
Yes but it wasn't new to me	137	16.49	
No but I have experienced this before	274	32.97	
No and I have never experienced this	332	39.95	
Missing	8	0.96	

a debate on a scientific topic

Response	Frequency	Percent	Mean: 3.08
Yes and it was a new experience	71	8.54	
Yes but it wasn't new to me	165	19.86	
No but I have experienced this before	219	26.35	
No and I have never experienced this	374	45.01	
Missing	2	0.24	

1

Response	Frequency	Percent	Mean: 1.88
a	0	0.00	
b	283	34.06	
c	136	16.37	
d	124	14.92	
e	45	5.42	
Missing	243	29.24	

2

Response	Frequency	Percent	Mean: 2.17
a	0	0.00	
b	202	24.31	
c	214	25.75	
d	182	21.90	
e	67	8.06	
Missing	166	19.98	

3

Response	Frequency	Percent	Mean: 2.81
a	0	0.00	
b	59	7.10	
c	244	29.36	
d	280	33.69	
e	212	25.51	
Missing	36	4.33	

4

Response	Frequency	Percent	Mean: 3.08
a	0	0.00	
b	47	5.66	
c	154	18.53	
d	288	34.66	
e	309	37.18	
Missing	33	3.97	

5

Response	Frequency	Percent	Mean: 2.61
a	0	0.00	
b	104	12.52	
c	239	28.76	
d	301	36.22	
e	142	17.09	
Missing	45	5.42	

6

Response	Frequency	Percent	Mean: 2.02
a	0	0.00	
b	181	21.78	
c	177	21.30	
d	95	11.43	
e	49	5.90	
Missing	329	39.59	

7

Response	Frequency	Percent	Mean: 2.04
a	0	0.00	
b	205	24.67	
c	186	22.38	
d	109	13.12	
e	58	6.98	
Missing	273	32.85	

8

Response	Frequency	Percent	Mean: 1.91
a	0	0.00	
b	228	27.44	
c	294	35.38	
d	98	11.79	
e	35	4.21	
Missing	176	21.18	

9

Response	Frequency	Percent	Mean: 2.08
a	0	0.00	
b	203	24.43	
c	222	26.71	
d	153	18.41	
e	49	5.90	
Missing	204	24.55	

10

Response	Frequency	Percent	Mean: 2.20
a	0	0.00	
b	223	26.84	
c	206	24.79	
d	181	21.78	
e	93	11.19	
Missing	128	15.40	

11

Response	Frequency	Percent	Mean: 2.34
a	0	0.00	
b	147	17.69	
c	256	30.81	
d	150	18.05	
e	113	13.60	
Missing	165	19.86	

12

Response	Frequency	Percent	Mean: 2.86
a	0	0.00	
b	62	7.46	
c	221	26.59	
d	284	34.18	
e	233	28.04	
Missing	31	3.73	

13

Response	Frequency	Percent	Mean: 2.06
a	0	0.00	
b	187	22.50	
c	245	29.48	
d	116	13.96	
e	55	6.62	
Missing	228	27.44	

14

Response	Frequency	Percent	Mean: 2.74
a	0	0.00	
b	73	8.78	
c	258	31.05	
d	268	32.25	
e	196	23.59	
Missing	36	4.33	

15

Response	Frequency	Percent	Mean: 2.44
a	0	0.00	
b	138	16.61	
c	262	31.53	
d	209	25.15	
e	125	15.04	
Missing	97	11.67	

16

Response	Frequency	Percent	Mean: 2.11
a	0	0.00	
b	199	23.95	
c	290	34.90	
d	117	14.08	
e	80	9.63	
Missing	145	17.45	

17

Response	Frequency	Percent	Mean: 2.64
a	0	0.00	
b	86	10.35	
c	269	32.37	
d	256	30.81	
e	160	19.25	
Missing	60	7.22	

18

Response	Frequency	Percent	Mean: 2.12
a	0	0.00	
b	197	23.71	
c	282	33.94	
d	160	19.25	
e	60	7.22	
Missing	132	15.88	

19

Response	Frequency	Percent	Mean: 2.45
a	0	0.00	
b	143	17.21	
c	266	32.01	
d	171	20.58	
e	148	17.81	
Missing	103	12.39	

20

Response	Frequency	Percent	Mean: 2.00
a	0	0.00	
b	175	21.06	
c	213	25.63	
d	76	9.15	
e	50	6.02	
Missing	317	38.15	

21

Response	Frequency	Percent	Mean: 2.97
a	0	0.00	
b	47	5.66	
c	204	24.55	
d	263	31.65	
e	275	33.09	
Missing	42	5.05	

22

Response	Frequency	Percent	Mean: 2.90
a	0	0.00	
b	44	5.29	
c	242	29.12	
d	243	29.24	
e	254	30.57	
Missing	48	5.78	

23

Response	Frequency	Percent	Mean: 1.59
a	0	0.00	
b	334	40.19	
c	196	23.59	
d	53	6.38	
e	17	2.05	
Missing	231	27.80	

24

Response	Frequency	Percent	Mean: 2.55
a	0	0.00	
b	187	22.50	
c	158	19.01	
d	203	24.43	
e	197	23.71	
Missing	86	10.35	

25

Response	Frequency	Percent	Mean: 1.80
a	0	0.00	
b	175	21.06	
c	369	44.40	
d	29	3.49	
e	15	1.81	
Missing	243	29.24	

26

Response	Frequency	Percent	Mean: 1.86
a	0	0.00	
b	193	23.23	
c	303	36.46	
d	59	7.10	
e	25	3.01	
Missing	251	30.20	

27

Response	Frequency	Percent	Mean: 2.39
a	0	0.00	
b	116	13.96	
c	222	26.71	
d	192	23.10	
e	81	9.75	
Missing	220	26.47	

28

Response	Frequency	Percent	Mean: 3.16
a	93	11.19	
b	204	24.55	
c	170	20.46	
d	198	23.83	
e	163	19.61	
Missing	3	0.36	

29

Response	Frequency	Percent	Mean: 2.23
a	312	37.55	
b	203	24.43	
c	173	20.82	
d	101	12.15	
e	42	5.05	
Missing	0	0.00	

30

Response	Frequency	Percent	Mean: 3.49
a	74	8.90	
b	125	15.04	
c	185	22.26	
d	210	25.27	
e	236	28.40	
Missing	1	0.12	

31

Response	Frequency	Percent	Mean: 2.99
a	180	21.66	
b	133	16.00	
c	210	25.27	
d	131	15.76	
e	176	21.18	
Missing	1	0.12	

32

Response	Frequency	Percent	Mean: 2.52
a	250	30.08	
b	174	20.94	
c	214	25.75	
d	106	12.76	
e	85	10.23	
Missing	2	0.24	

Appendix 3
Epistemological Beliefs Assessment for Physical Science
(EBAPS)

EPISTEMOLOGICAL BELIEFS ASSESSMENT FOR PHYSICAL SCIENCE (EBAPS)

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1. Introduction
2. Intended 'audience'
3. Why another epistemological assessment?
4. Subscales
5. Items (Go here for the actual survey)
6. Logistics and scoring

Introduction

EBAPS is a forced-choice instrument designed to probe students' *epistemologies*, their views about the nature of knowledge and learning in the physical sciences. It was initially developed and validated by Andrew Elby, John Frederiksen, Christina Schwarz, and Barbara White at the University of California, Berkeley.

Intended 'audience'

EBAPS is aimed at high school and college students taking introductory physics, chemistry or physical science. It's optimized for algebra-based courses. A versions of EBAPS suitable for purely conceptual courses (often aimed at liberal arts majors) is under development.

Why another epistemological assessment?

The Maryland Physics Expectations Survey (MPEX), developed by the Physics Education Research Group at the University of Maryland, and the Views about Science Survey (VASS), developed by Halloun and Hestenes at Arizona State University, probe a combination of students' epistemological beliefs and their course-specific *expectations* and study habits. In addition, those surveys work best if students' intuitive epistemologies take the form of consistent and articulate beliefs. Although epistemology and expectations cannot be completely disentangled, EBAPS attempts to focus on epistemology to the extent possible, and also attempts to probe tacit, contextualized epistemological knowledge that may affect students' learning behavior. For more details, including the justification for, development of and validation of EBAPS, please see the Idea Behind EBAPS, a mini-paper. Section 3 of that paper discusses **validity and reliability**.

Subscales

EBAPS probes students' views along five non-orthogonal dimensions:

1. *Structure of scientific knowledge*. Is physics and chemistry knowledge a bunch of weakly connected pieces without much structure and consisting mainly of facts and formulas? Or is it a coherent, conceptual, highly-structured, unified whole?

2. *Nature of knowing and learning.* Does learning science consist mainly of absorbing information? Or, does it rely crucially on constructing one's own understanding by working through the material actively, by relating new material to prior experiences, intuitions, and knowledge, and by reflecting upon and monitoring one's understanding?

3. *Real-life applicability.* Are scientific knowledge and scientific ways of thinking applicable only in restricted spheres, such as a classroom or laboratory? Or, does science apply more generally to real life? These items tease out students' views of the applicability of scientific knowledge *as distinct from* the student's own desire to apply science to real life, which depends on the student's interests, goals, and other non-epistemological factors.

4. *Evolving knowledge.* This dimension probes the extent to which students navigate between the twin perils of absolutism (thinking all scientific knowledge is set in stone) and extreme relativism (making no distinctions between evidence-based reasoning and mere opinion).

5. *Source of ability to learn.* Is being good at science mostly a matter of fixed natural ability? Or, can most people become better at learning (and doing) science? As much as possible, these items probe students' epistemological views about the efficacy of hard work and good study strategies, *as distinct from* their self-confidence and other beliefs about themselves.

Items

You can view all 30 EBAPS items on the web, color-coded by subscale, or sorted by subscales. (The subscale sort also includes the scoring scheme, discussed below.) And, you can download a student-usable version of the survey in Microsoft Word format.

Logistics and scoring

Most students need 15 to 22 minutes to complete EBAPS. Scantron forms are recommended.

Each item is scored on a scale of 0 (least sophisticated) to 4 (most sophisticated). The scoring scheme is non-linear to take into account question-by-question variations in whether, for instance, neutrality is more or less sophisticated. A subscale score is simply the average of the student's scores on every item in that subscale. (When an item within a given subscale is left blank, the average is calculated without that item included.) Sometimes we multiply through by 25 in order to report subscale scores on a scale of 0 to 100.

To automate the scoring using Microsoft Excel, see the instructions and download the Excel scoring template.

Appendix 4
The Idea behind EBAPS

THE IDEA BEHIND EBAPS

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- 3.1. Formulating the instrument
- 3.2. Validity testing
- 3.3. What about reliability?

4. Critique of EBAPS

Footnotes

References

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1. Introduction

We want an instrument optimized for probing the epistemological stances of students taking introductory physics, chemistry, and physical science. Three popular surveys seem like promising candidates. One is Schommer's (1990) Epistemological Questionnaire (EQ), which is designed to apply to all disciplines and a broad range of age groups. The others, aimed specifically at college and advanced high school *physics* students, are Redish *et al.*'s (1998) Maryland Physics Expectation survey (MPEX) and Halloun & Hestenes' (1998) Views About Science Survey (VASS) In their respective communities, these surveys have brought unprecedented attention to epistemological issues. However, they contain important flaws. Schommer's EQ accurately probes students' epistemological stances *toward physical science* only to the extent that epistemological stances are stable *beliefs* or *traits* or *theories* that don't depend heavily on context, disciplinary or otherwise. As Hammer & Elby (2001) argue, this assumption is problematic. Consequently, we want an instrument that "works" whether or not students' epistemological stances depend on context. MPEX satisfies this condition in some respects but not in others. Also, by design, it probes not only students' views about knowledge and learning, but also their non-epistemological, course-specific beliefs about how to get high grades.

For these reasons, we designed a new survey, the Epistemological Beliefs Assessment for Physics Science (EBAPS). In section 2, we critique Schommer's EQ and Redish *et. al.*'s MPEX. These criticisms, which apply to other multiple-choice epistemological assessments currently in the literature, provide guideposts for designing a new instrument. Section 3 discusses how we formulated and validated EBAPS. In section 4, we critique EBAPS, acknowledging the ways in which it falls prey to some of our criticisms of other instruments.

2. Critique of other epistemological instruments

In this section, we critically examine Schommer's Epistemological Questionnaire (EQ) and Redish *et al*.'s Maryland Physics Expectation survey (MPEX). We single them out for criticism *solely* because they are well-known in their respective communities and because our arguments apply equally well to other multiple-choice epistemological instruments.

2.1 Critique of Schommer's EQ [1]

EQ's strength—and in our view, its weakness—is the generality of its items, such as

- Nothing is certain, but death and taxes.
- I don't like movies that don't have endings. [2]

(Other questions focus more specifically on school and learning, but without specifying a disciplinary or other rich context.) This generality might be problematic, for the following reason. As science educators and teachers, we want to know the extent to which students see scientific knowledge as certain versus tentative and evolving, among other issues. However, a student's reaction to the "death and taxes" item gives us accurate insight into her view of scientific knowledge only if students have stable *beliefs* or *theories* about certainty—beliefs that apply just as well to science as they do to everyday events or whatever else the student has in her head when she responds to the item. Hammer & Elby (2001) argue that this assumption is problematic. This assumption is plausible. For instance, as Hofer shows, students thinking about chemistry view knowledge as more certain than students thinking about psychology do. Even within a specific discipline, people's view of certainty might fluctuate. For instance, we are quite certain that the Earth is round (as opposed to flat), but quite uncertain about whether life exists on Mars. Hammer & Elby show that other contextual factors might also matter. [3]

Similar criticisms apply to the movie item. A student's response gives us precise insight into her view of scientific knowledge only if the student possesses a general tolerance or intolerance for uncertainty that permeates her view of knowledge in various disciplines. In other words, the movie item assumes that epistemological stances are *traits*; But epistemological stances, like many personality characteristics, might be less monolithic. For instance, we know a calm person who always becomes agitated and angry when she spends time with a certain annoying relative. Similarly, someone who dislikes ambiguity while relaxing at the movies on Saturday night might revel in uncertainty (after a good sleep) when debating a complex policy issue.

In summary, the extent to which Schommer's EQ accurately probes students' epistemological stances toward physical science depends on the extent to which epistemological stances are stable, context-independent *beliefs* or *traits*. We would prefer an epistemological instrument that works reasonably well even if students' epistemological stances turn out to incorporate disciplinary and other contextual dependence.

2.2. Critique of Maryland Physics Expectations Survey (MPEX)

MPEX, like EQ, asks subjects to rate their agreement/disagreement with brief statements. But the statements refer specifically to physics, and in many cases, to introductory physics courses. Examples include

- All I learn from a derivation or proof of a formula is that the formula obtained is valid and that it is OK to use it in problems.
- In this course, I do *not* expect to understand equations in an intuitive sense; they just have to be taken as givens.
- Knowledge in physics consists of many pieces of information, each of which applies primarily to a specific situation.

Even if students don't possess context-independent beliefs about the coherence of knowledge, these items probe whether they see *physics* knowledge *in their course* as coherent or piecemeal. However, many MPEX items conflate students' beliefs about knowing and learning with course-specific expectations and goals. For instance, MPEX tallies as “unsophisticated” a student who agrees with

- My grade in the course will be primarily determined by how familiar I am with the material. Insight or creativity will have little to do with it.

Unfortunately, in fast-paced pre-medical physics courses that emphasize rote application of algorithms, a student may agree with this statement even though she knows that *understanding* physics involves insight and creativity. See Hammer's "Ellen" (1989) for a case study.Ellen would probably also agree with

- A significant problem in this course will be being able to memorize all the information I need to know.
- It is possible to pass this course (get a “C” or better) without understanding physics very well.

MPEX underestimates that student's epistemological sophistication. Similarly, a student's answer to

- I plan to go over my class notes carefully to prepare for tests in this course

probably reflects her goals and time constraints just as much as it reflects her views of learning. In summary, many MPEX--by design--taps into students' expectations and goals regarding the course, as opposed to their purely epistemological stances. The point of the above comments is that a student's expectations and epistemology can be out of alignment; see Elby (1999).[5] That's why teachers and researchers who want to focus on *epistemology* need another instrument.

3. Design principles for a new epistemological instrument

In this section, we discuss the design heuristics underlying EBAPS. Then, we outline how the assessment is scored, and how we did validity testing.

3.1. Formulating the instrument

The four authors started with an extensive literature review of epistemology research, reading papers and discussing most of them during weekly meetings. Synthesizing other researchers' ideas, we arrived at the following guiding principles:

Multiple dimensions. Our items fall into five epistemological dimensions, discussed below. As Schommer argues, it's productive for researchers to analyze students' epistemological stances in terms of dimensions. See Hofer and Pintrich for a full interpretive review of this issue. Importantly, experts *disagree* about whether these dimensions are reified cognitive *structures* inside students' heads or merely analytical categories for researchers. [6]

Multiple item types. EQ, MPEX, and many other assessments rely solely on Likert-scale "agree/disagree" items. But. We use three different item types:

i. Likert-scale agree/disagree items;
ii. Multiple choice items
iii. Debate items.

Disciplinary specificity. Following MPEX and other discipline-specific instruments, EBAPS items relate directly to science and science learning, focusing on physical science. That way, whether or not epistemological beliefs depend on discipline, our assessment probes epistemological beliefs *regarding physics and chemistry.*

No `obvious' answer. Because physics instructors often preach about the real-life applicability of physics, alert students know they are *supposed* to agree with the MPEX item, "Learning physics helps or will help me understand situations in my everyday life." We attempt, probably with mixed success, to pose items that students do not perceive as having an obvious sanctioned answer.

Rich contextualization: Hammer & Elby (2001), diSessa (1985), and others argue that epistemological "beliefs" are not always explicit, articulate, and consciously-held. Some epistemological knowledge, they argue, is implicit and inarticulate—more like procedural knowledge than like beliefs. For instance, according to Hammer (1994), few students hold conscious *beliefs* about the truth or falsehood of

- Knowledge in physics consists of many pieces of information, each of which applies primarily to a specific situation. [MPEX item]

Most students have never pondered this abstract issue. But their implicit "opinions" can be probed with closely-related items connected directly to students' experiences—items about which students *have* an opinion or at least a gut reaction. For instance, consider this EBAPS item:

- Of the following test formats, which is best for measuring how well students understand the material in physics and chemistry? Please read each choice before picking one.

  - (a) A large collection of short-answer or multiple choice questions, each of which covers one specific fact or concept.

  (b) A small number of longer questions and problems, each of which covers several facts and concepts.

(c) Compromise between (a) and (b), but leaning more towards (a).

(d) Compromise between (a) and (b), favoring both equally.

(e) Compromise between (a) and (b), but leaning more towards (b).

Students *have* opinions (or at least gut reactions) about which exams are fair tests of their understanding. These opinions sheds light upon their (perhaps unarticulated) stances about the abstract issue of coherence vs. pieces. Of course, even if a student *does* hold a conscious belief about “knowledge in physics consists of many pieces,” her responses to our "best exam" item (and related items) sheds light on that belief. [7] The point is, we designed EBAPS to accurately probe students' epistemological stances concerning physical science whether or not epistemological beliefs depend on context (disciplinary and otherwise), and whether or not some epistemological knowledge is implicit (rather than belief-like or theory-like).

3.2. Validity testing

Above, we discussed the difficulty of probing students' purely epistemological beliefs, as distinct from their expectations about a particular course, their goals as learners, their own study habits, and so on. Our validity testing focused on this issue. Specifically, after a making two sets of revisions based on pilot subjects and informal feedback, we got about one hundred local community college students [8] to complete our assessment and write down their reasons for responding as they did to each item. [9] We then coded the responses looking for non-epistemological content.

It is instructive to review an item that got invalidated:

- Often, a scientific principle or theory just doesn't make sense. In those cases, you have to accept it and move on.

Several subjects who agreed wrote that, when they first encounter a hard new concept in a fast-paced class, they often “accept and move on,” but then go back later and try to make sense of it after they have more background. So, their agreement stems not from epistemological naivete, but from reasonable survival and learning strategy. The new version of the item may do a better job of getting at students' views about the coherence:

- Often, a scientific principle or theory just doesn’t make sense. In those cases, you have to accept it and move on, because not everything in science is supposed to make sense.

This kind of validity testing has the ability to pinpoint issues deserving further study. For instance, in response to our item “When it comes to learning science, memorizing facts is extremely important,” some students wrote that it depends on whether they're taking biological or physical science. Apparently, some students hold explicitly discipline-specific stances towards this issue.

3.3. What about reliability?

When developing instruments such as EBAPS, researchers often do reliability testing. Specifically, to make sure the items within a given subscale all probe the same beliefs, researchers refine or replace items that do not correlate with the others. We are not using this technique, for a principled reason. We don't want to assume that each subscale corresponds to a stable, consistent belief (or set of beliefs). For instance, consider these two items:

- When learning science, people can understand the material better if they relate it to their own ideas.
- If physics and chemistry teachers gave *really clear* lectures, with plenty of real-life examples and sample problems, then most good students could learn those subjects without doing lots of sample questions and practice problems on their own.

If both items pass further validity testing, and if students' responses correlate poorly (e.g., if most students agree with both items, even though the favorable repsonse ot the second item is disagreement), it's *not* necessarily because one of the questions is “bad.” It might be because students are neither principled constructivists nor principled absorptionists. For this reason, the EBAPS subscales should be viewed as targets for instruction, not as categories of beliefs residing in students' heads.

Indeed, if students' epistemologies consist not of "beliefs" but of more fine-grained cognitive resources whose activation depends on context, then we *expect* students to disagree with themselves, so to speak, about different items in the same subscale. Again, consider the two Nature of Learning items listed above. The question about students' own ideas might trigger the idea that knowledge is something built up (an idea they've abstracted from real-life experiences constructing knowledge), and hence the idea that relating scientific concepts ot their own ideas is productive for learning. The lecture question, by contrast, might trigger the idea that knowledge is "transmitted stuff," and hence, that really clear transmission is sufficient for learning. As discussed in a cognitive theory/practice paper, it's likely that students "have" the idea of knowledge as transmitted stuff *and* the idea of knowledge as built-up stuff; and which idea gets activated in a given moment depends on contextual cues. By allowing students to disagree with themselves within a given subscale — i.e., by not considering this disagreement on its own to indicate "unreliability" in the EBAPS items — we enable EBAPS to probe a range of contexts relevant to learning physical science.

4. Critique of EBAPS

In section 2, we critiqued other epistemological instruments. In this section, we show how EBAPS fails to escape completely the criticisms we raised, despite our best efforts. Future revisions of EBAPS will alleviate some of these problems. Other problems with EBAPS (and EQ and MPEX) are probably a fundamental part of any multiple-choice instrument designed to probe a complex set of beliefs. For this reason, we think that EBAPS and other such instruments are best used *in addition to* interviews, case studies, and other methodologies that probe students' beliefs more deeply.

Major problems with EBAPS include the following:

Teasing epistemology apart from expectations. Our validity testing suggests that it's extremely difficult to write items that probe *purely* epistemological beliefs in nearly *all* respondents. For instance, even though

- Someone who doesn’t have high natural ability can still learn the material well even in a hard chemistry or physics class.

passed our validity tests, it's likely that some students answered “no” largely because they've never taken a challenging science course. In other words, some of our items probably trigger students' expectations about their classes *and* their epistemological beliefs, in ways invisible to the student herself, and hence, invisible to our validity testing. Deeper interviews would alleviate this problem, but not vanquish it entirely. Furthermore, even our “cleanest” items typically elicited non-epistemological reasoning from one or two subjects (out of the 50 or so).

Teasing beliefs apart from goals. Our item

- Someone who doesn’t have high natural ability can still learn the material well even in a hard chemistry or physics class

is meant to probe students' views about the efficacy of effort. But a student could disagree simply because he doesn't want to put effort into his difficult physics class, and "convincing" himself that effort wouldn't make a difference anyway helps him rationalize his actions.

Inferring students' sophistication. We count as "sophisticated" agreement with

- Given enough time, almost everybody could learn to think more scientifically, if they really wanted to.

But a student could agree for unsophisticated reasons, such as believing that learning to think scientifically is no harder than learning to write cursive—it's just a matter of raw practice with no deeper cognitive change.

Inviting stock responses. An early version of EBAPS contained the item, “When it comes to learning science, memorizing facts is extremely important.” But since physics teachers often preach about the evils of “memorizing,” many students know that they're *supposed* to disagree. For that reason, we changed the wording (and for independent reasons, flipped the valence) to

- When it comes to understanding physics or chemistry, remembering facts isn’t very important.

Even so, some students probably know that they're *supposed* to agree.

Footnotes

[1] Hofer and Pintrich (1997) raise some of these issues.

[2] Using a Likert scale, students rate their agreement or disagreement with each item.

[3] A philosopher being treated for angina is quite certain, in all relevant senses, that her heart exists and pumps blood. But in an abstract academic discussion, the same philosopher may argue convincingly that

scientific theories about the cardiovascular system are not certain. The philosopher's response to Schommer's item can and should depend on whether she's in a practical or an academic mindset.

[5] Some EQ items, such as “Everyone needs to learn how to learn,” also tap into values and goals.

[6] For instance, Schommer talks in terms of reified factors, while Hammer (1994) explicitly argues that his “axes” are not reified cognitive structures corresponding to stable beliefs.

[7] If a student's belief about pieces vs. coherence does *not* correlate with her beliefs concerning practical issues such as the textbook and exams, then that abstract belief is “empty,” not useful for predicting and explaining students' behavior.

[8] Drawn from six separate community colleges in northern California, these subjects were ethnically and socioeconomically diverse, judging by feedback obtained from the professors and by data about the student populations of those colleges. We did not collect data about ethnicity or SES.

[9] Each subject wrote out their reasoning for *half* the items in our 38-item survey.

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Appendix 5
Alignment between SLOs for Natural Science Assessment and EBAPS Statements
(Faculty Survey Analysis)

HW Natural Sciences SLO's vs EBAPS statememts

SLO	EBAPS Statement Number	HWC SCIENCE PROFESSORS Experts						Total Count
		1 and 2	3	4	5	6	7	
1	1						X	1
	2	X			X		X	4
	3	X		X	X	X		4
	4							0
	5	X	X	X				4
	6	X	X					3
	7	X	X		X		X	5
	8		X					1
	9							0
	10	X						2
	11	X	X	X		X		5
	12	X				X		3
	13	X	X	X	X			5
	14	X	X	X				4
	15							0
	16							0
	17	X	X	X	X			5
	18	X	X		X			4
	19	X	X			X		4
	20	X	X					3
	21	X					X	3
	22	X	X	X		X		5
	23						X	1
	24	X	X	X	X	X	X	7
	25					X	X	2
	26					X	X	2
	27	X					X	3
	28		X					1
	29	X	X	X	X	X		6
	30	X	X				X	4
	31	X	X					3
	32	X				X	X	4
2	1					Y	Y	2
	2							0
	3						Y	1
	4	Y		Y			Y	4
	5						Y	1
	6					Y	Y	2
	7	Y					Y	3
	8	Y					Y	3
	9			Y		Y	Y	3
	10	Y					Y	3
	11				Y			1
	12	Y					Y	3
	13					Y		1
	14							0
	15							0
	16			Y				1
	17	Y						3
	18				Y	Y		2
	19			Y		Y		2
	20	Y			Y			3
	21							0
	22	Y				Y		3
	23			Y				1
	24						Y	1
	25							0
	26					Y		1
	27	Y			Y	Y		4
	28					Y	Y	2
	29					Y	Y	2
	30					Y	Y	2
	31						Y	1
	32	Y		Y				3
3	1	Z		Z	Z		Z	6
	2							0
	3		Z				Z	2
	4					Z		1
	5		Z			Z		2
	6		Z	Z	Z			3
	7		Z		Z	Z	Z	4
	8	Z	Z	Z	Z	Z	Z	7
	9					Z		1
	10							0
	11		Z		Z			2
	12			Z				1
	13		Z					1
	14		Z					1
	15		Z			Z		2
	16							0
	17	Z	Z			Z		4
	18		Z					1
	19	Z				Z		3
	20	Z	Z	Z	Z			5
	21		Z			Z		2
	22	Z	Z		Z			4
	23							0
	24		Z					1
	25							0
	26					Z		1
	27							0
	28					Z		1
	29		Z			Z	Z	3
	30		Z	Z	Z	Z	Z	5
	31		Z		Z		Z	3
	32							0
4	1	W	W					3
	2	W	W	W	W	W	W	7
	3	W	W		W			4
	4							0
	5	W	W					3
	6	W			W			3
	7	W	W	W				4
	8	W	W					3
	9	W						2
	10	W		W	W			4
	11	W	W			W		4
	12	W						1
	13	W	W					3
	14	W				W		3
	15	W		W				3
	16	W				W		3
	17	W	W					3
	18	W	W	W				4
	19	W			W	W		4
	20	W	W			W		4
	21	W	W	W				4
	22	W	W			W		4
	23	W				W	W	4
	24	W	W			W		4
	25	W				W	W	4
	26	W				W	W	4
	27	W		W	W			4
	28	W				W		3
	29	W	W			W		4
	30	W	W		W			4
	31	W	W	W	W		W	6
	32					W	W	2

Appendix 6
Means and Standard Deviations of Axes and SLO Expert Responses among Students Who Have Only Taken Natural Science Courses at HWC

Means and Standard Deviations of Axes and SLO Expert Responses among Students who have *only* taken Natural Science Courses at HWC

		SLO 1		SLO 2		SLO 3		SLO 4	
	N	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
no college science courses	423	41.01	19.830	55.2	33.55	51.75	27.216	45.56	17.468
1-2 HWC science courses (no science courses taken at other colleges)	108	44.29	18.953	57.41	31.928	54.53	27.270	48.26	18.305
3+ HWC science courses (no science courses taken at other colleges)	38	54.26	18.604	61.84	31.696	65.32	25.624	54.74	16.375

		Axis 1		Axis 2		Axis 3		Axis 4		Axis 5		Axis 6	
	N	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
no college science courses	398	35.56	23.29	41.34	20.09	50.65	30.99	34.67	31.80	50.25	30.89	46.61	40.40
1-2 HWC science courses (no science courses taken at other colleges)	108	34.92	23.64	46.16	19.72	55.37	30.52	37.50	32.87	55.32	31.80	50.46	40.73
3+ HWC science courses (no science courses taken at other colleges)	38	46.47	25.43	53.03	21.21	62.63	30.20	43.42	31.13	65.79	26.90	63.16	36.18