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2aEDa7. Application of active-learning techniques to enhance student-based learning objectives

Tracianne B. Neilsen* and Kent L. Gee

***Corresponding author's address: Physics and Astronomy, Brigham Young University, N311 ESC, Provo, Utah 84602, tbn@byu.edu**

Research in physics education has indicated that the traditional lecture-style class is not the most efficient way to teach science courses at the university level. Current best-teaching practices focus on creating an active-learning environment and emphasize the students' role in the learning process. Several of the recommended techniques have recently been applied to Brigham Young University's acoustics courses. Adjustments have been built on a foundation of establishing student-based learning outcomes and attempting to align these objectives with assessments and course activities. Improvements have been made to nearly every aspect of the courses including use of class time, assessment materials, and time the students spend out of the classroom. The progress made in bringing two of the courses, specifically an introductory, descriptive acoustics course for a general audience and a junior level introduction to acoustics course for majors, is described. Many of the principles can be similarly applied to acoustics education at other academic levels. Suggestions are made for those seeking to modernize courses at their institutions.

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Introduction

Over the past few years, the authors have been making changes to two acoustics courses at Brigham Young University (BYU). The first class is an introductory, general education class entitled "Descriptive Acoustics" (Physics 167). The second is a small, upper level class, entitled "Introduction to Acoustics," (Physics 461) designed for physics and engineering students who are particularly interested in preparing for careers in acoustics. These changes have been driven by the need to define learning outcomes for the university accreditation process, an interest in physics education research, and a desire to enhance student participation and learning.

BYU, similar to many schools, has been pushing instructors to move away from course objectives and establish learning outcomes. The learning outcomes focus on skills and knowledge that the students acquire in the class.[1] Ideally each course would have 3-5 learning outcomes that would in some way be measurable through assessments, such as papers, exams, etc. The learning outcomes for the two undergraduate acoustics classes at BYU are listed in Table I.

Table 1 Learning outcomes for the general education "Descriptive Acoustics" class and the upper-level "Introduction to Acoustics."

Descriptive Acoustics	Introduction to Acoustics
Define the basic terminologies of acoustics and identify physical principles involved in common situations. Solve basic problems and answer conceptual questions related to hearing, speech, audio, listening environments, and musical instruments.	Demonstrate a conceptual and mathematical understanding of acoustical phenomena, including source radiation, sound transmission, absorption, and reflection.
Apply a few key scientific models to solving acoustical problems in many areas including hearing, speech and musical instruments.	Calculate appropriate measures of sound, including sound pressure level, transmission loss, sound power, weighted levels, and noise criteria.
Display an ability to write effectively by properly using the terminology of acoustics and logically outlining how acoustics is important in a discipline of their choice.	Perform acoustical measurements, interpret the data, and document the results in the form of technical laboratory reports.

Figure 1 Course integration triangle.[2]

Education research often centers on one or more of the three pillars of pedagogy shown in Figure 1.[2] The interplay of activities, instruction and assessment all need to promote student-based learning objectives. Most of the accepted "best-practices" in science education encourage the instructor to engage the student in ways that allow the student to actively participate and not merely absorb information through a lecture-style format. Such an approach is described as creating an active-learning environment for the course.

Many books and articles have been written with good ideas for achieving an active-learning environment.[3,4,5,6,7] The authors' position is that there is not a single best practice and the potential for each technique is determined by the teacher's personality and teaching style, the subject matter being taught, and the backgrounds of the students themselves. It is beneficial to look at a wide variety of ideas and then find things that work for a specific instructor for a specific course.

Examples of active-learning techniques applied in the introductory "Descriptive Acoustics" course and the upper-level "Introduction to Acoustics" course are now given.

Descriptive Acoustics

A recent paper, accepted for publication in the special issue of *JASA* on Education,[8] gives a detailed description of the introductory class and explains the assessments and some of the activities. A short description of the class is given followed by a discussion of the newest aspect of the course: pre-class learning activities.

"Descriptive Acoustics" is a general education science course that was designed to provide a conceptual understanding of acoustics and how it relates to a wide variety of topics, particularly in hearing, speech, and music instruments. The majority of the students are majoring in music, sound recording, or speech and communications disorders, however there is a variety of other majors represented, including a few engineering, physics and physics teaching majors each semester. Typically there are 60-100 students in the class, which is taught in a large lecture hall. The scope of the class is described in the learning objectives in Table 1 and covers most of the chapters in *Music, Speech, Audio* by Strong and Plitnick.[9]

To facilitate an effective learning experience during class, it is essential that the students come prepared. It would be ideal if the students would read, take notes on the material, and prepare questions to ask during the class discussion. In reality, this rarely happens because the students are busy with other things. It is necessary to require a graded assignment on the new material due prior to class to motivate them to consider the topics to be discussed in class.

As described in Ref. 8, reading quizzes have been used for the introductory class until this semester. Each reading quiz consisted of 3 multiple choice questions based on the main topics in the assigned chapter from the textbook. They were primarily definition-based questions. In an attempt to approach the JITT methodology recommended by Novak, *et al*,[5] the reading quizzes were replaced this semester by pre-class learning activities (LA). The LAs were designed to provide the students with meaningful exposure to the concepts before class. An LA consists of a hands-on interaction either with a simulation/applet on their computer[10,11] or a small experiment. While general directions are provided, the LA is not completely scripted. The goal is to provide enough information that they know what to do but then to let them follow their own curiosity in completing the activity.

Each LA concludes with the assignment for the student to write a paragraph about their experience or observations. A list of 3-5 items of things they should address in their writing is provided to guide them. For example, the LA where they explore the "Wave on a String" Phet simulation[11] has some preliminary directions regarding how the simulation works and ends with "Spend five minutes exploring the interactive simulation and write a paragraph about your experience that includes the following. Describe, in your own words, frequency, amplitude, damping, and wave speed." For each LA, students are required to use at least three technical words from the chapter in their response. Examples of other LA are listed in Table 2, and electronic copies of all the LA are available from the authors via email.

Table 2 Examples of pre-class learning activities used in the "Descriptive Acoustics" class. Electronic copies of all the learning activities are available upon request via email at tbn@byu.edu.

Compare and contrast the clarity, quality and dynamic range of two acoustic transducers you use every day.
Explore sound transmission and absorption by placing an alarm in an open/closed box with and without stuffing.
Experience the "cocktail party."
Perform a Diagnostic Rhyming Test in your living room with varying levels of background noise.
Perform the spaghetti-raisin resonance demo and figure out how it applies to the anatomy of the ear.
Make a mechanical reed instrument out of a straw.
Make an instrument out of a cup and string.

The LA is submitted electronically one hour before class. As with the JITT approach, the professor scans the responses to find common misconceptions that merit discussion during class. Examples of these misconceptions and a few well-written correct statements are chosen to share with the students. Currently these selected sentences are handed out as true/false questions and included in the class discussion. Some examples of the student responses for the "Wave on a String" activity are included in Table 3. This semester, verbal "true" or "false" responses were solicited from the students during the class discussions, and students were invited to explain their reasoning.

Table 3 Student responses when asked to define frequency, amplitude, damping and wave speed after exploring the "Waves on a string" demo.[11]

T or F:	Frequency is a measure of how fast a wave passes a single point.
T or F:	The amplitude is the height of the peaks of the wave.
T or F:	Damping decreased the longevity of the wave.
T or F:	As we increased the amplitude of the oscillations, it increased the wave speed.
T or F:	Increasing the tension increases the frequency.
T or F:	As the frequency increased, the wave speed decreased.
T or F:	As the frequency increased, the wave speed is faster.

Feedback from the students at the end of the semester was interesting. Overall, they enjoyed the learning activities and found them helpful. Some students described their experiences as follows:

- "I've found that the learning activities help motivate me to really study the text and understand the concepts we are learning."
- "I actually enjoyed a lot of the learning activities because performing the experiments and playing with the simulators showed how the things we are learning are actually applied in terms that matter in everyday life, and the simulators gave the mind a good feel for how certain variables worked with each other."
- "I'd say that my overall experience with the learning activities was one of helpful, real-world application. On occasion, a learning activity would crop up that I would consider somewhat simplistic, but on the whole, they were very informative and gave insight that otherwise could not have been gained."
- "Overall I had a pretty good experience with learning activities. There were a lot that were helpful to my learning and made the corresponding lecture much easier to understand."

As one might expect, about half the class preferred the simulations/applets, while the other half preferred the physical activities. One useful suggestion was that a short preview of the LA be given at the end of the class prior to the due date, so students would have a better idea of what was needed. While foam ear plugs were supplied for the LA about hearing protection, it appears that items such as straws, plastic cups, string, paper clips, rubber bands, etc. need to be provided since, apparently, many college students do not have these items readily available. Because the six lowest LA scores were dropped to accommodate any possible situations or excuses, those without the materials did not complain but mentioned that they would have completed the LA if they had the objects.

While the authors are supporters of the goals behind our university's "Writing Across the Curriculum" program,[12] it was interested to see that some of the students also valued the experience of having to put their observations into words. One student remarked, "Writing up the paragraph forced me to actually read and understand the different technical words that were related to the unit, which helped my overall understanding of the topic."

It was almost unanimous that they enjoyed going over student responses in class as long as it did not take up too much time. As the semester progressed, it was not clear to the professor that the students were enjoying this technique, so handouts of student responses were used less frequently as the semester progressed. This needs to be changed in the future. One student's comment is representative of many: "I found it very helpful when you spent time discussing students' LA responses. It was helpful because it allowed me to hear the same definitions from a college student's point of view. It put things into perspective and often, I would understand a peer's definition of a term better than the book's. I particularly liked it when you passed out sheets with the true/false answers on it because I was able to take note on them and refer to them in preparation for exams. I'll admit, I was rather disappointed when you started providing the handouts less frequently in unit 2 and almost never in unit 3."

The other interesting, repeated comment about the use of student responses in class was that because I posed them in T/F format and tried to guide them to the answer via student comments, some students were not always exactly sure if the response was true or false. While I wish they would have just raised their hand to clarify it at the time, I plan to address this in the upcoming semester by using an electronic peer response system to collect the student responses to the T/F questions. This should reveal the correct answer clearly, encourage attendance (although I had at least 80% attendance most of the semester), and hopefully help those seated in the back portion of the class to participate more.

Introduction to Acoustics

The learning activities (LA) and assessments in the advanced undergraduate physics course naturally take on a different form than in the descriptive course discussed thus far. However, their purpose is the same: to promote active engagement by the students in reaching the student-centered course objectives. Four examples are provided.

First, the relatively small class size (10-15 students) facilitates the use of board work as an LA. This has been used to perform example calculations, to practice the use of mathematical skills, and to promote physical understanding of concepts or equations found in the reading. For example, spherical waves are discussed in Chapter 5 of *Fundamentals of Acoustics, 4th ed.*[13] As part of the discussion, the specific acoustic impedance of a spherical wave is introduced and expressed in Eq. 5.11.12 as

$$\boldsymbol{z} = \rho_0 c \frac{(kr)^2}{1+(kr)^2} + j\rho_0 c \frac{kr}{1+(kr)^2} \, .$$

The students, in groups of two, are asked to go to the board and to take the limits of the expression for $kr \gg 1$ and $kr \ll 1$. (No attempt is made to explain the significance of kr at this point.) After the students are reminded of how one goes about taking a limit, they are usually quick to the answer for $kr \gg 1$, $\boldsymbol{z} \approx \rho_0 c$. The students are then asked where they have seen this, and they are fairly quick to respond that it is the characteristic impedance of the medium. With further prompting, they are also reminded that this is the characteristic impedance for a plane wave. This naturally leads to a discussion of the physical significance of kr and the definition of the far field.

The situation changes somewhat when the students are asked to take the limits for $kr \ll 1$. In three semesters of teaching this concept this way, the students almost always mentally replace kr with zero, and show that the impedance is zero. After a short discussion and a little more effort, the students see that the real part of the impedance goes to zero more quickly than the imaginary part, and soon arrive at $\boldsymbol{z} \approx j\rho_0 ckr$. This results in a discussion of resistance versus reactance, of near versus far fields, phase between pressure and particle velocity, and intensity, all of which are very important concepts throughout the remainder of the course. This is one example where a relatively simple board exercise (3-4 lines of algebra) can be used to help students learn to find physical insight in mathematical expressions.

A second type of classroom LA in the advanced course could be described as interactive learning demonstrations (ILD), similar to those developed by Thornton and Solokoff.[7] Sometimes this involves an actual physical demonstration and other times an adaptable animation that involves a mathematical model being used in class (e.g., examining reflection and transmission through a layer.) A new physical demonstration ILD developed for Fall 2011 involved measuring the directivity of one or two loudspeakers in class using a real-time spectrum analyzer (in our case, a Larson Davis 824 meter), as shown in Fig. 2. Three scenarios were planned, but only two were carried out because of time limitations.

First, broadband noise was input into one speaker. Each student was given a piece of polar graph paper and an assignment to keep track of the sound level in a different one-third octave band as the microphone was moved through different angles. Of course, the students tracking low-frequency bands saw little variation. However, at high frequencies, a more directional response was noted, including distinct lobing at some frequencies. In the future, we may supply pre-selected individual tones that exhibit interesting directional patterns, rather than noise, given the tendency of the latter signal to smear out the directivity function for high-frequency bands.

The second experiment used identical broadband noise fed into two loudspeakers wired 180° out of phase. Students were given the same instructions, and although the predicted dipole pattern was clearly seen at low frequencies, students were surprised to see other patterns when the source size and separation became relatively large. Figure 3 shows a student's plots for the 4 kHz one-third octave band for one speaker (note the directionality) and for two out-of-phase speakers (two distinct nulls). Students learned first-hand about directivity, but also to take the assumptions made in mathematical models (such as a dipole) seriously. Additional experiments could involve two speakers receiving the same signal, but now *in* phase, and two loudspeakers receiving two incoherent noise signals, but equal in amplitude. We predicted what the directional response might look like from these two cases, but did not test our predictions for these cases. The latter example, in particular, was planned and would be helpful, as students continually struggle with the concept of coherent and incoherent addition of sound waves.

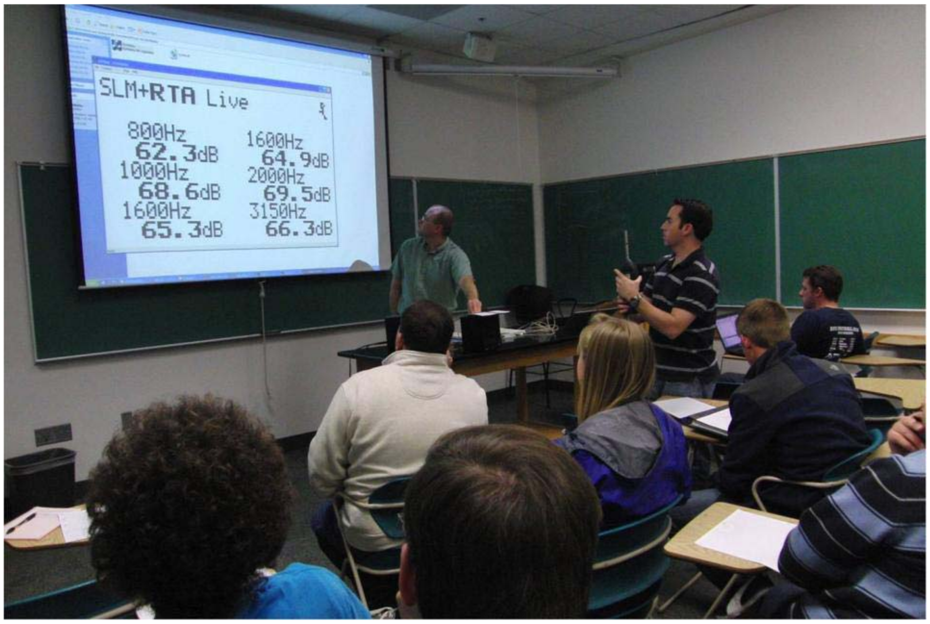

Figure 2 Interactive lecture demonstration of the directivity of a dipole using a Type I sound level meter.

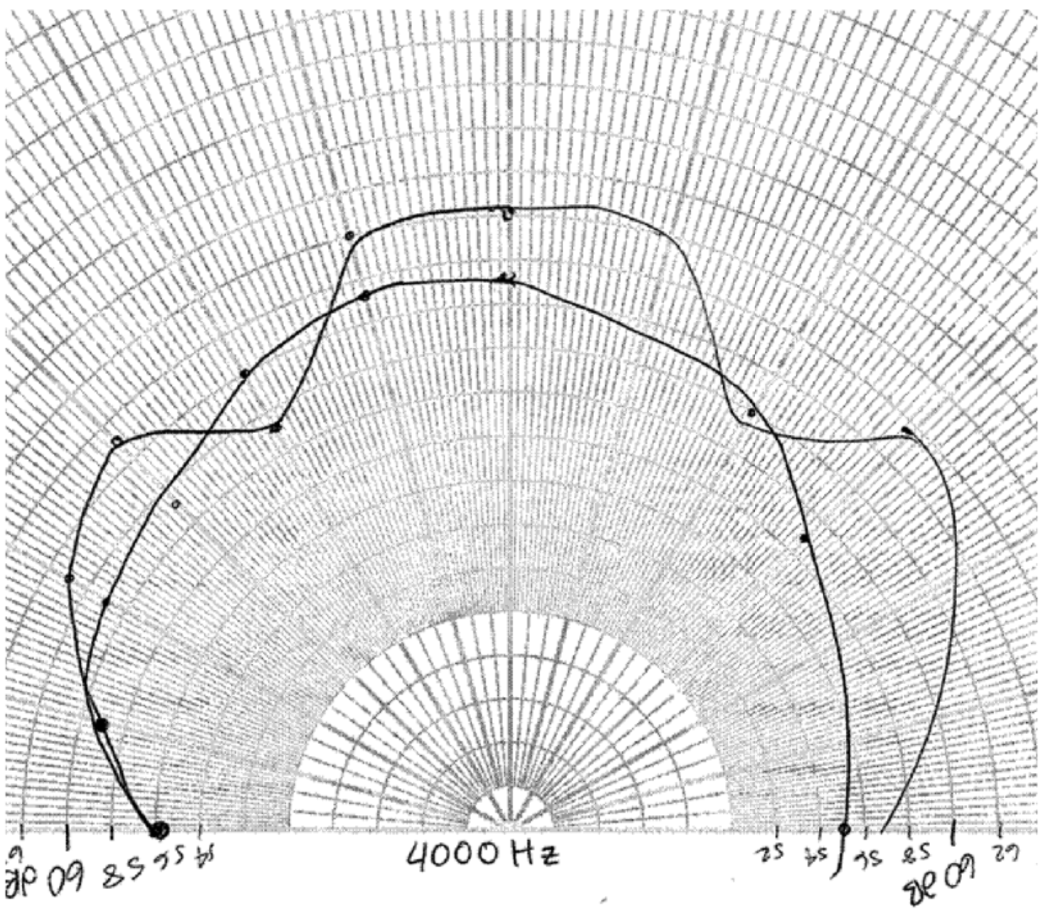

Figure 3 Student's plot of the directivity at 4000 Hz of one loudspeaker (no significant lobing) and two out-of-phase loudspeakers (nulls at ~15°).

Active learning can also be promoted by helping students make connections between the concepts taught and everyday life. Consequently, much emphasis is placed on helping students see how they can use mathematical models to solve real-world problems. For example, students have been required to apply their understanding of an infinite line source made up of discrete, incoherent monopoles to estimating the sound level from traffic. For reference,[14] given a sideline distance of r, a source separation distance of b, and a monopole sound power of Π_M, the radiated mean-square pressure for $r > 3b$ is $\langle p^2 \rangle = \frac{\rho_0 c \Pi_M}{4br}$. On the unit exam, the students were given a picture similar to Fig. 4, and the following scenario:

The sound power level radiated by the average truck at highway speeds is 108 dB re 1 pW. The sound power level radiated by the average car is 100 dB re 1 pW. For steady traffic flow, given an average distance between any two vehicles of 20 m and the fact that there are three cars for every truck, calculate the sound pressure level from this flow of traffic at a sideline distance of 500 m. Hint: Consider how you could separate this problem into individual incoherent discrete line sources that can then be summed.

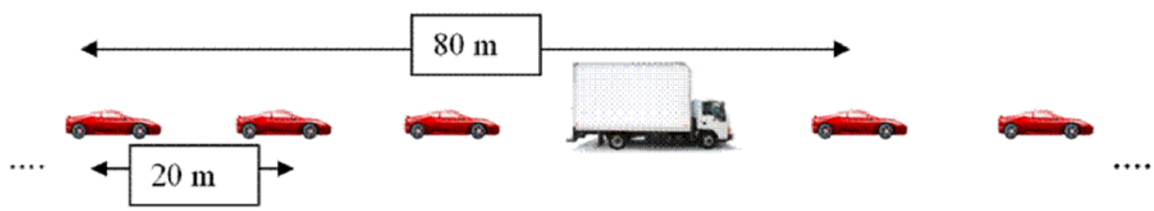

Figure 4 Diagram used for traffic modeling problem.

The figure itself is meant to serve as a hint to how one might approach the problem, by breaking the problem into four incoherent line sources, three of which are identical, and the fourth representing the trucks. The problem itself is not very mathematically intensive. However, the creativity of the students in finding correct solutions to the problem was impressive. Some students approached the problem as suggested by the figure. Others, however, treated the traffic as two sources, by saying that the trucks are comprised of an equivalent car (100 dB re 1 pW) and a "light" truck. This allowed them to now say that all the cars are separated by 20 m and there is an additional line source (the "light" truck) with a separation of 80 m. Other students found the *average* separation distance of the cars before calculating the radiation of that line source and from that of the truck. The students were excited when we compared the various approaches jn class and they saw that they were equivalent. This and other practical problems involving, e.g., noise at football stadiums, transmission loss through walls of homes, and diffraction around highway barriers help to empower students as they realize they can tackle (at least in simplified form) the sorts of problems that acoustical consultants are required to handle.

The fourth active learning method applied has been the use of labs that, again, treat real-world problems. Two of these labs have involved class projects to make community noise measurements, one from a skate park near a residential development in Eagle Mountain, Utah and the other a study of the levels produced in and around the BYU football stadium during a game. The students are then assigned to analyze portions of data or help in writing the report.

In the case of the skate park analysis, the students were assigned to read the report the instructor had written, provide at least ten edits each, and to write drafts of the executive summary. The report was delivered to the City of Eagle Mountain at the conclusion of the semester. These experience help students learn through hands-on measurements and in the writing of professional-style technical memos and reports.

Conclusion

Skeptics of physics education research often ask what is to be gained by putting forth the extra effort to develop and use active-learning techniques in a classroom. While a study by Hake[15] did show a difference in exam scores between a traditional, lecture-style class and a more interactive class, a switch to active-learning techniques has not been universal among educators. Regardless of the exam scores, there are some tangible, albeit anecdotal, differences that have made this a worthwhile endeavor for the authors. First, the class is more enjoyable for the students. The students tend to be more enthusiastic about the course, which prompts them to follow their curiosity to learn more about the subject. Further, once they have tasted of the excitement that comes from exploring new material—not just for an assignment but out of a desire to learn more—they are more likely to enjoy learning in the future. Second, the attitude of the students in the class translates directly into the reputation of the class. For anyone worried about enrollment figures, this is a good thing. Three years ago, the "Descriptive Acoustics" class was dropped as a requirement for the Speech and Communications disorders majors at BYU, which had accounted for about 40% the students taking the class. Although there was an appreciable drop in enrollment for the first two years, this year the enrollment has almost regained its previous level.

Another point that is often made by skeptics is that active learning activities take up too much time and that by using them the instructor cannot cover as much material. While it is unreasonable to expect anyone to incorporate a significant activity learning component into a course the first time they teach it, once the instructor is familiar with the course, its material, and its general student population, the addition of active learning techniques can significantly enhance a course without "watering down" the content. This is particularly true when the students come to class better prepared, which allows for class-time activities to be designed more effectively. Note that in modifying the structure of the "Descriptive Acoustics" courses over the past couple of years to create a more active-learning environment, the average exam scores have not fallen and appear to be up by around 2%.

The advanced undergraduate "Introduction to Acoustics" class has been offered for four years now and was designed from the ground up to promote an active-learning environment. The balance of mathematical rigor and theory with real-world application and hands-on experiments has been appreciated by the students. During class, students have made comments such as "For the first time in college I feel like I'm actually learning something useful" and "This class blows my mind, but it is so much fun!" Despite their difficulties with the material, the students readily seek the challenge of new educational opportunities when they understand that they are gaining significant experiences that lay the foundation for their future careers.

[1] Brigham Young University has placed a great deal of emphasis on learning outcomes as can be seen at http://learningoutcomes.byu.edu (Viewed 21 March 2011.) Guidelines for writing learning outcomes can also be found at this page.

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