What are the limits of validity in science? new lab class to improve scientific literacy of humanities students

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Abstract
In 2007, Tohoku University started a new laboratory class designed for students in humanities courses, which is aimed at teaching "knowledge about science" (knowledge of the scientific process) towards improved scientific literacy. We present here one typical theme of the class, "String oscillation and music: the universality and diversity of culture", together with responses from the students.

Keywords: PISA, Scientific literacy, Knowledge about science, Context-based learning, Evidence-Based-Decision.

Resumen
En 2007, la Universidad de Tohoku comenzó una nueva clase de laboratorio diseñado para los estudiantes en los cursos de humanidades, que tiene como objetivo la enseñanza de "conocimientos sobre la ciencia" (conocimiento del proceso científico) hacia la mejora de la alfabetización científica. Presentamos aquí un tema típico de la clase, "La oscilación de cuerdas y música: la universalidad y diversidad de la cultura", junto con las respuestas de los estudiantes.

Palabras clave: PISA, Alfabetización Científica, Conocimientos sobre la ciencia, Aprendizaje basado en el contexto, Desición Basada Evidencia.

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I. INTRODUCTION

"What are the limits of validity?" Such a question is indispensable for research in physics, especially in theoretical physics [1]. "What are the limits of validity in science?" This question is indispensable for all citizens. Citizens without scientific competency will naturally ask science (i.e., scientists) what science "cannot" uncover, often resulting in mutual mistrust and chaos in decision-making of a science-related social/personal issue (see, for example, Sample item in the OECD-PISA 2006, "Catching the killer") [2].

As such, the level of scientific literacy, in particular, knowledge about science, (knowledge of the scientific process) is regarded as a main target of the OECD-PISA survey on scientific literacy [3]. However, in spite of its importance, little material exists specific to the teaching of knowledge about science [4], because traditional teaching has mainly been designed for providing an education in the knowledge of science. In this paper, we report our new-laboratory class designed to teach knowledge about science for humanities students.

II. HISTORICAL BACKGROUND

In 2004, Tohoku University started a new laboratory experiment program for students enrolled in science courses [5]. With its success as an educational program for about 1,800 freshmen per year, we planned a further laboratory program specially designed for humanities students.

From professional experience, those in the department of science are familiar with the design of suitable lab classes for science students; however, such knowledge is lacking in terms of teaching humanities students. Thus, before setting out the details of the lab class, we discussed with professors in humanities to find out what and how we should teach such a class. From these surveys, we reached some strategic conclusions on the background and purpose of the class, as summarized below.

A. Background of the class:

1) Modern society is based on the findings of science, which in turn involves the study of nature. Thus, an understanding of nature through experiment and observation is important to understand the basis of modern society.

2) For humanity sciences that deal with humanity and society, it is not possible to conceptualize any future society without considering the role of science and technology.

B. Achievement objectives

1) Students can investigate nature through experiments and observation.

2) Students can learn about the logical aspect of the natural sciences by understanding the principles of nature.

3) Students can experience natural phenomena that are utilized in everyday life in modern society.

We have devised 10 themes from the topics of “earth and environment”, “energy”, “life”, “science in our daily life”, “science and culture”, and “mathematics as the backbone of natural science”. The laboratory for humanities students (faculties of Arts and Letters, Education, Law and Economics) has been running since 2007.

III. MUSIC FOR LAB EXPERIMENT

We present here one of the 10 themes: “String oscillation and music: the universality and diversity of culture” [6]. As discussed in the Introduction, there currently exists little material or experience in teaching knowledge about science. As physicists, we are familiar with teaching about the universality of science. For example, when physicists teach “physics and music”, many concentrate on the universality among different phenomena that physics can uncover. However, in this case, such a conventional approach was not considered to be sufficient as educational material for knowledge about science, because humanities students are very interested in the diversity of culture.

In principle, music has both aspects: universality that scientific evidence can uncover, and diversity depending on value judgment that scientific evidence cannot uncover. In reality, students have a huge variety in their music preferences. In this sense, we think that music is an ideal subject to teach the limits of validity of science, a key concept in the “knowledge about science”.

As teaching material to demonstrate the diversity aspect, we utilize two musical scales: the just temperament scale (natural scale)” and the equal temperament (artificial scale)”. These scales differ in that the frequency ratios of two different pitches in the scale are, in general, rational (in the case of just temperament) and irrational (in the case of equal temperament). By comparison of the two musical scales, we expect students to find both the value of science and the limits of its validity.

IV. LAB EXPERIMENT

The experiment consists of three parts, where the total duration is three hours. The first part provides an introduction as guidance. The second part demonstrates the universality of physics and its application to music. The final part discusses the variety of the musical scale, built upon the knowledge of universality obtained in the second part.

Practice 1 (Workshop)

In the first part of the practice, we discuss with students some topics concerning the limits of the validity of science, including the concept of “evidence-based decision making” for issues such as climate change, choice of medical therapy [7] etc. Here, we make students aware of the phenomena in which science itself cannot directly determine the decision. We also use a sample item of the OECD Programme for International Student Assessment 2006 (PISA2006) [2], which tests the level of scientific literacy, in particular, the subject’s competency in identifying scientific issues, i.e. differentiating between scientific issue and issues that are not related to science [3]. Since Japanese students have, in principle, never been tested on their competency in identifying a scientific issue, they are quite amazed at the question.

As an introduction to “Music and Physics”, we then ask students some questions about universality:

1. Why is a musical scale discrete?
2. Why is the musical scale developed in traditional Western music largely applicable to other regions?
3. Why are the three tones Do, Mi, and Sol, considered the special set in musical harmony (major chord)?

Next, we show the two musical scales, the “Just Temperament” and the “Equal Temperament” scales, and ask students, “Does it make any sense to ask which musical scale is better?”

Practice 2 (Universality)

In the second part of the lab, students carry out experiments using classical guitars. First they learn about the physics of string oscillation, in particular the concept of a “mode” of oscillation, which is closely related to the emergence of a musical scale. We decided not to use any scientific instruments in the experiment because of the wish for students to understand the natural laws intuitively. With the exception of the guitars, the only other instruments used are tape measures and tuners, so the students can even perform these experiments at home (Fig. 1).

By using the technique called “harmonics (flageolet)” (Fig. 2), students create sounds from mode 1 to mode 6, and find that the natural musical scale (just temperament) emerges in accordance with a natural law. Since the natural law is independent of the region and time, students realize why the musical scale has universality. For further details on universality, please refer to our previous paper [5].

Practice 3 (Diversity)

In practice 2, students realize that natural musical scale (just temperament) has universality and is widely used. But in many countries, including Japan, other musical scales are also used, for example, the equal temperament scale. Students are then asked why equal temperament, an artificial music scale, was introduced. In order to discuss this issue, they are requested to clarify the character of the two musical scales, using their knowledge of science.

FIGURE 1. Through the use of simple instruments, students become familiar with experiments and natural laws.

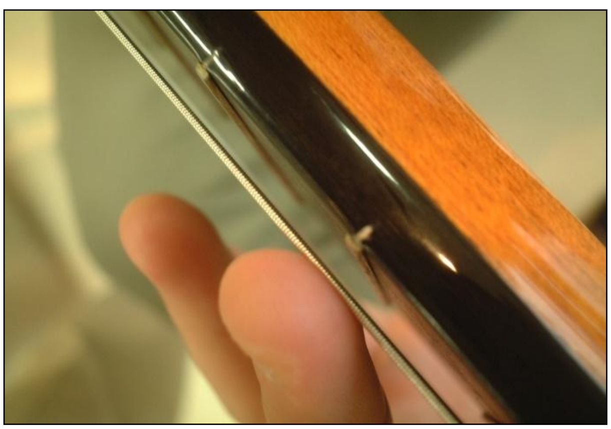

FIGURE 2. By touching the node of a wave mode, students can create and hear harmonics by themselves.

To make quantitative comparison between the two musical scales possible, students calculate the frequencies of the tonic chord (Do, Mi, Sol) in the two different scales (just temperament and equal temperament). They thus find the difference of the frequencies of the pitches with the same names in the different scales.

Since the difference in frequencies is less than 1%, in our previous lab class designed for science students, many students presumed that such a small difference was negligible. Therefore, to check such a naïve presumption with the results of a theoretical calculation, students perform a verification experiment.

FIGURE 3. Students are comparing Equal Temperament and Just Temperament with the aid of a teaching assistant.

In the verification experiment, students simultaneously make the sounds of Mi (English pitch name is E) both in the equal temperament by the conventional way (using the 1st string of the guitar) and in just temperament using the harmonic technique (using the 6th string). From observation by using their own ears, students can intuitively identify the difference in tone, through the existence of a beat tone. The beat tone can be confirmed intuitively, despite the difference in frequencies being less than 1%. Students are then requested to tune the 1st string that was initially set in equal temperament, in order to match the two frequencies, using the fact that the beat tone vanishes when the frequencies of the two tones coincide (Fig. 3). When the two frequencies coincide, students measure the frequency of the 1st string and find that the frequency has decreased in accordance with their calculation of the frequencies of the pitch in the two musical scales.

With these results, the students are expected to understand the characteristics of the two musical scales, which science can uncover (Fig. 4).

With all the scientific evidences that the students have found by themselves, they are then asked to compare the difference in the characteristics of the two musical scales, especially with regard to their perceived merit or demerit. The result is shown on Fig. 4.

In the guidance material, we asked students, "Does it make sense to ask which musical scale is better?" The result (Fig. 4) clearly shows that it does not make sense. The choice of musical scale does depend both on the situation and value judgment, which varies individually. Since the diversity of the value judgment is beyond the universality of science, students are expected to find the limit of the validity of science in this scenario.

Evidence from experiments	Harmony (chord) without beat tone	Freedom of change in key (e.g. C Major → F Major)
Just temperament	○	×
Equal temperament	×	○

FIGURE 4. Characters of the two musical scales, where circle and cross mean merit and demerit, respectively.

V. RESPONSE OF STUDENTS AND FUTURE TASKS

In this paper, we presented a trial to teach the limits of the validity of science in a laboratory class. With the questionnaire survey, we have confirmed that this theme is effective for educating in scientific literacy; 51% showed strong interest while only 6% had little interest (2008).

Although the new lab class is generally successful, there are some issues to be resolved to improve it further. We dedicate three hours for this theme, but the duration is not long enough to complete it in its current form because of the detailed content. We will therefore have to trim some of the content or find a way to teach the material more effectively. Since there may be many subject areas other than music which will be suitable to teach the limits of the validity of science, we expect readers to find and develop their own. We hope that our trial offers a hint of the potential to develop new lab classes for improved scientific literacy.

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