Developing Cloud Chambers with High School Students

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Abstract
The result and outcome of the cloud chamber project, which aims to develop a cloud chamber useful for science education is reported in detail. A project includes both three high school students and a teacher as a part of Super Science High School (SSH) program in our school. We develop a dry-ice-free cloud chamber using salt and ice (or snow). Technical details of the chamber are described. We also argue how the project have affected student’s cognition, motivation, academic skills and behavior. The research project has taken steps of professional researchers, i.e., in planning research, applying fund, writing a paper and giving a talk in conferences. From interviews with students, we have learnt that such style of scientific activity is very effective in promoting student’s motivation for learning science.

1 Introduction
Since the Fukushima nuclear accident on March 2011, the requirement of teaching radiation has been significantly increasing in Japan. However, recent surveys\cite{1,2,3,4} show that experiments or measurements concerned with radiation are rarely done in a classroom. In order to improve such a situation, an easy, safe and inexpensive experiment will play a key role. One may agree that the diffusion cloud chamber experiment\cite{5,6,7} meets most requirements for the purpose mentioned above. Indeed, it is reported\cite{1} that the cloud chamber experiment is most popular among radiation related experiments.

While the experiment is simple enough, there may also be some inconveniences which prevent a teacher from bringing it into a classroom. One such inconvenience is the use of dry ice. Even in Japan, there are many cities where obtaining dry ice is not so easy. Even if available, dry ice can not be kept for a long time. A teacher has to order dry ice day by day for a long term use. To overcome this difficulty, various dry-ice-free experiments have been developed \cite{8,9}. In this article, we would like to explore the possibility of using ice and salt to cool a cloud chamber. The remarkable advantage of our method is that both ice and salt are easily available and can be stored for a long time. Moreover, they are very familiar to us. Our city, Yokote is famous for traditional snow dome called Kamakura, therefore is abundant in snow. A particular kind of salt
is spread on the winter roads as road salt to avoid freezing. In fact, authors used to wonder whether snow can be used for cloud chamber while doing experiments using dry ice or liquid nitrogen. This strong motivation leads us to develop a cloud chamber using ice and salt.

![A snow dome Kamakura.](image)

This paper also aims to identify educational effects of student research project. Our project launched January 2011 as an activity of science club, with support from the Super Science High School (SSH) program in our school. The team consists of a teacher (S.Z.) and three high school students who are also authors of this paper. Students first determined their research subject, applied for some research funds, wrote a paper and presented their result in more than five conferences. A presentation in an international conference in Taiwan was given in English. Providing a realistic environment for research can be regarded as an example of situated learning proposed by Lave and Wenger [10]. Such strategy is applied in most SSH schools in Japan, since its effectiveness to motivate students and to develop scientific skills has become evident. A survey [11] reported that student’s motivation for learning science is significantly enhanced by an experience of a spontaneous research project organized by themselves. It was also reported that an experience of research affects students careers [12]. We would like to identify changes in students, ideas about science, career and scientific research through interviews with students.

| Name                  | Place                  | date       |
|-----------------------|------------------------|------------|
| SEES2012               | I-shou university, Taiwan | Aug. 2012  |
| Science conference    | Akita university       | Oct. 2012  |
| Tohoku SSH conference | Sendai 3rd High School  | Feb. 2013  |
| JSPS junior session   | Hiroshima university   | Mar. 2013  |
| SSH conference         | Yokohama               | Aug. 2013  |
2 A cloud chamber using ice and salt

2.1 Ice-salt cooling bath

It is well known that table salt melts ice and the mixture of salt and ice (the cooling bath) becomes colder after salt added. This phenomena, freezing point depression, is common to various salts other than table salt (sodium chloride). Our first mission is to find a better salt which shows greater performance in cooling than a table salt. We choose two salts, calcium chloride dihydrate (CaCl$_2$.2H$_2$O) and magnesium chloride hexahydrate (MgCl$_2$.6H$_2$O) as our candidates, since they are known to perform better than table salt [13] and are also available at low cost as road salts. Figure 2 compares the performance of two salts for cooling. The experiment is done by adding a particular amount of salt to 100g of crushed ice in a polystyrene foam tray. Measurements were done for ten minutes for each amount of salt to record lowest temperature reached. It turns out that MgCl$_2$.6H$_2$O shows better performance for cooling than CaCl$_2$.2H$_2$O. The best performance is obtained when we add 60g of MgCl$_2$.6H$_2$O, in which the temperature of the mixture reached $-22$ °C.

![Figure 2: Performance evaluation of two salts.](image)

2.2 Construction of a chamber

After some trials for constructing a cloud chamber for an ice-salt cooling bath, we learned that the design of the bottom plate for cooling is not straightforward. First, heat capacity of bottom plate should be small since the ice-salt slush is not as cold as dry ice. It is very difficult to see particle tracks unless the chamber is neatly designed. Second, the bottom plate and the slush should be kept in contact. If one simply put a chamber onto slush, it floats on the slush and becomes unstable. To overcome these problems, we designed a cloud chamber as Fig. 3. The bottom plate is made of thin aluminum. In order to avoid the chamber float, legs are attached at four corners of the bottom plate. As shown in right side of Fig. 3 we pour the ice-salt slush around chamber so that it is kept in contact with the bottom plate.

2.3 Observation of the tracks

We would like to describe an observation of particle tracks using the ice-salt cooling bath (MgCl$_2$.6H$_2$O is employed) and the chamber described above. The whole apparatus is shown in Fig. 4. The interior of the chamber is covered by a piece of black felt soaked with ethanol. A video projector is used as a strong light source. Temperature of some places inside the chamber is measured by a thermocouple. A lantern mantle
Figure 3: The bottom of the cloud chamber.

Figure 4: The whole apparatus.
is placed in the chamber as an alpha particle source. A digital SLR camera is used to record video of particle tracks. The room temperature was around 25°C.

With this setting, we succeed in observing particle tracks as seen in Fig. 5 although the number of tracks is quite less than that of a dry ice experiment. A result of more quantitative analysis using a video image is shown in Fig. 6 in which a 10 minutes run is recorded. A track longer than 2cm is counted. 41 tracks are observed per minute. The vertical line in figure shows a period in which we apply voltage by approaching charged plastic ruler from the outside of the chamber. Apparently a count increases when voltage is applied. It is also remarkable that tracks remain visible even when the bottom of the chamber rises up to −16°C.

3 Educational effects on students

3.1 History of the research project

As mentioned in the introduction, our project begins as a part of SSH program of our school which is largely supported by MEXT and JST. An inquiry based class (100
minutes per week, 1 year) and science club activity (an hour per day, 1.3 years) were spent for research. In accordance with the very high requirement of SSH, students had worked hard to accomplish their research goal. In our case, the goal is to observe particle tracks with the ice and salt chamber. It was very close to the deadline of Japan Student Science Award (JSSA), which is one of the most important scientific award in Japan, that they succeeded in observing particle tracks.

The teacher (S.Z.) assumed that, it is very important not to give detailed instruction to students in order to make their activity spontaneous. Actually, most parts of the project were conducted by themselves. The teacher gave minimum instructions for experimental technique (use of liquid nitrogen) and theoretical issue (vapor pressure). In particular, the theory of droplet nucleation is far beyond the high school physics curriculum. It is surprising that they learned it themselves and plotted the vapor pressure after minimum instruction of Mathematica. Among conference talks listed in Table 1.

![Figure 7: A poster talk in JPS junior session on Mar. 2013](image)

...the poster presentation in junior session of Japanese Physics society was very impressive. Their effort to give the best presentation was rewarded by both a good presentation award and also responses from researchers. We did not expect many responses from physicists since the cloud chamber is no longer used as a real research tool for particle physics. It is surprising that our presentation drew interests not only from physics education researcher but also experimentalists. A professor kindly informed us of a B.S. thesis that is not published. Through this experience, we have learned the importance of having opportunity for communicating with other researchers to obtain up-to-date information and forming a community for particular research topic. Such opportunities largely depend on the support from SSH for travel expenses, which are not available in ordinary school.

### 3.2 Interviews

The strategy of the research project, providing environment and opportunities as close as possible to a graduate student physics lab, is common for SSH Schools in Japan.
According to the literature \[14,11\], motivation for learning and mastering science increases if what students do is under their control. In this section, we would like to present a result of an interview with three students in order to evaluate educational effects of our project. Interviews was carried out from 9 to 12 July, 2013. Each students spent about 20 minutes to answer seven questions. The questions are:

| 1. Can you find any differences between usual lectures in science class and our project research? |
| 2. Have you grown up through this project? If so, in what sense? |
| 3. Do you think that you did your own project which is not assigned or forced from our school? |
| 4. Have you accomplished something great? |
| 5. Did you find any difficulties to accomplish your mission? |
| 6. Did you find any difference between peers or teachers in your school and professional researchers met in conferences? |
| 7. What do you think about speaking, reading and writing English in our project? |
| 8. Has your idea about radiation changed after finishing our project? |

Answers by the students are summarized in table 2. In most questions, answers from three students are essentially common and coincide with teacher’s expectation. In Q. 1, all students agreed that the freedom allowed to them was the exclusive feature of the project that is very different from usual class. In Q. 2, all students claimed the importance of planing research schedule in order to lead their collaboration to success. They also mentioned that their communication skills were enhanced through interactions between project members and opportunities of conference talks. For example, they said that it was not easy to make appointment with each other. They have learned that it is important to manage their schedule. In Q. 4, Two students were satisfied with their success of developing their cloud chamber. Answers to Q. 5 are very impressive, because all students agreed that communication with other members was major difficulty they confronted. They implied a small trouble between them during research, also they have not told its content. For Q. 6, they also told that they need more knowledge and academic skill for realistic research. They also agreed that the experience of an international conference helps them to understand that English is necessary for scientific research in Q. 7. In Q. 8, they said that they understood that the risk of radiation essentially depends on its amount. All of them agreed that it is wrong to be afraid of radiation without considering its amount and kind. There are two answers that contradict with teacher’s expectation. They are shown in italic in Table 2. Both are from a student who
Table 2: Classification of answers to questions. In all questions, answers from three students can be classified to one or two kinds, which we denote answer 1 and 2.

| Q. | Answer 1                                      | Answer 2                       |
|----|-----------------------------------------------|--------------------------------|
| (1)| Making decision on their own                  |                                |
| (2)| Skill to plan research                        | Communication skill            |
| (3)| Same as Q. (1)                                |                                |
| (4)| Success in their observation                  | Not so much                    |
| (5)| Relationship with other members               | No time for meeting            |
| (6)| Amount of knowledge                           | Critical comments              |
| (7)| Important                                     | Valuable experiences           |
| (8)| Not so dangerous                              | Not changed so much            |

most contributed to and lead the entire project with very strong motivation. For Q. 7, he answered that he surprised only little with the first success of observation, since it can be expected from the theory and literature. He also claimed that he had only gained a little knowledge of radiation since our project is rather focused on the development of a chamber than the physical aspects of radiation. These two issues were intended by the teacher to lead our project to success in limited time. It is clear that he realized that teacher’s intention, had more interests with physics itself, and wanted to achieve a higher goal than the teacher expected. As is clear from this example, students has begun to think critically both for their research plan and also physics itself.

Discussions

From the interviews with students, it turns out that providing an opportunity of realistic research is very effective to promote their motivation for science and to develop technical and social skills required for scientific research. Although our program depends on large support from SSH, some aspects will be useful for non-SSH schools. Opportunities for local conferences will available at relatively low cost. Finding enough time for research will be very difficult except for science club students. However, it is still possible to design inquiry based activity within usual physics class, although time will be very limited. Assigning student research project during summer vacation is also a good idea. In any case, giving enough freedom to students to choose their subject is important.

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