Chapter 15
A Case Study of a Science Teacher in a Science Club Teaching Scientific Inquiry

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15.1 Introduction

Science fairs give students the opportunity to select interesting problems to solve as science projects. They brainstorm to discuss a variety of topics in order to then identify an exciting idea for their investigation (Barry and Kanematsu 2006). It is recognized by many educators that science fairs help students discover topics of interest, design experiments to investigate science problems, and provide the first steps on the ladder to success (Mann 1984). For example, students who enter the Westinghouse Science Talent Search frequently go on to have careers in scientific fields (Marsa 1993), and students who have participated in science fairs report that this experience influenced their career choices in science (Olson 1985). Many science educators believe that participation in science fairs helps students develop the attitudes, skills, and knowledge that will help them to fit in and be successful in a scientific and technological society.

The first student science fair in the United States was held in 1928. After becoming a national event in 1950, they became more widespread (Bellipanni and Lily 1999). In 1958, the fair became international for the first time, when Japan, Canada, and Germany joined the competition. Today, the Intel International Science and Engineering Fair (Intel ISEF) is the world's largest international pre-college science competition, and it annually provides a forum for more than 1500 high school students from about 70 countries, regions, and territories to showcase their independent research. Every year, millions of students worldwide compete in local and school-sponsored science fairs. The winners of these events go

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on to participate in ISEF-affiliated regional and state fairs, from which the best wins the opportunity to attend the Intel ISEF. The Intel ISEF unites these top young scientific minds, showcases their talent on an international stage, enables them to submit their work for judging by doctoral level scientists, and provides them with the opportunity to compete for over $3 million in prizes and scholarships. The China Adolescents Science and Technology Innovation Contest (CASTIC) is the national science fair in China, and it is affiliated with the ISEF. CASTIC has had a strong influence on the way students study and select science pathways (Li 2008). Each year, teachers and parents encourage hundreds of thousands of students to enter science fairs, and, according to official figures released earlier this year, 15 million students participate in CASTIC at all levels (CASTIC 2012). Both team projects and individual projects are allowed to participate in the CASTIC. CASTIC provides an annual forum for more than 500 students from middle school to high school to showcase their independent research in 16 categories including biology, chemistry, engineering, and math.

Teachers play a key role in students' research during the course of their science projects. Science clubs give teachers an opportunity to select student researchers and to provide systematic guidance to them regarding appropriate methods of scientific inquiry (Galen 1993). Therefore, encouraging teachers to encourage students who are interested in science to engage in science-fair projects and use science clubs to organize their research can effectively improve the scientific literacy of students.

This study examines the strategies used in a science club by a science-fair-award-winning teacher to instruct talented senior high school students in scientific inquiry and then gives some suggestions to other teachers who want to guide students to participate in the science fair.

15.2 Rationale and Theoretical Framework

The cognitive apprenticeship theory was developed by Collins et al. (1989), who based it on the situated cognition learning theory. Cognitive apprenticeship differs from traditional apprenticeships in that the tasks and problems are chosen to illustrate the power of certain techniques or methods and to give students practice in applying these methods in diverse settings. The complexity of tasks is gradually increased so that component skills and models can be integrated. In cognitive apprenticeship, conceptual and factual knowledge is demonstrated within each specific context. The term *cognitive apprenticeship* refers to the fact that the focus of learning through guided experience is on cognitive and metacognitive development, rather than on physical skills and processes.

Based on the theory of cognitive apprenticeship, a framework is used to describe four dimensions of a learning environment: content, method, sequence, and sociology. Relevant to each of these dimensions is a set of characteristics that should be considered when constructing learning environments. The characteristics of content include domain knowledge, heuristic strategies, control strategies, and learning strategies. The characteristics of methods include modeling, coaching, scaffolding, articulation, reflection, and exploration. The characteristics of sequence include increasing complexity, increasing diversity, and the placement of global skills before local skills. The characteristics of sociology include situated learning, the culture of expert practice, intrinsic motivation, exploiting cooperation, and exploiting competition.

Collins et al. (1989) developed six teaching methods rooted in the cognitive apprenticeship theory and claimed that these methods help students attain cognitive and metacognitive strategies for "using, managing, and discovering knowledge" (Brown et al. 1989). The first three (modeling, coaching, and scaffolding) provide the core of cognitive apprenticeship and help with cognitive and metacognitive development. The next two (articulation and reflection) are designed to help novices with awareness of problem-solving strategies and execution, similar to that of an expert. The final step (exploration) is intended to guide the novice toward independently solving and identifying problems within the domain (Collins et al. 1989).

Collins published a paper about learning environment in 1993. In this paper, he discussed the advantages and disadvantages of modeling, coaching, scaffolding, articulation, and reflection, which are the basic teaching methods (Collins 1993). Collins continued to develop the theory of cognitive apprenticeship. In 1997, Collins published a paper about cognitive apprenticeship and the changing workplace. In this paper, Collins pointed out that students can learn content and skills while conducting a complex task and that the situation based on the goal was also one kind of cognitive apprenticeship (Collins 1997).

In 2006, Collins published a paper on cognitive apprenticeship again in the *Cambridge Handbook of the Learning Sciences*. In this paper, he described the new development of situated learning, community of practice, scaffolding, articulation, and reflection. After continuous research and reflection, Collins revised the framework of the cognitive apprenticeship theory. He deleted exploiting competition from sociology and changed the culture of expert practice into community of practice. Cognitive apprenticeship focuses on four dimensions that constitute any learning environment: content, method, sequencing, and sociology (Collins 2006).

Content means the types of knowledge required for expertise. It includes four parts which are domain knowledge, heuristic strategies, control strategies, and learning strategies. Methods refer to ways to promote the development of expertise. It includes six parts which are modeling, coaching, scaffolding, articulation, reflection, and exploration. Sequencing refers to keys to ordering learning activities. It includes three levels which are increasing complexity, increasing diversity, and global to local skills. Sociology refers to social characteristics of learning environments. It includes four parts which are situated learning, community of practice, intrinsic motivation, and cooperation.

15.3 Research Questions

Within the framework of cognitive apprenticeship developed by Collins et al. (1989), this study intends to answer the following question: What are the guiding strategies of an award-winning teacher to prepare students for CASTIC? How does the teacher organize and manage the science club?

15.4 Methodology

15.4.1 Participants

The subjects of this study were members of a science club, which included the students and the instructor who was a junior high school teacher in Shanghai city. The science club, which was called the "Biology and Environment Science Club," consisted of students who were interested in science and research. Typically, there were 20–25 students in this science club a year. The teacher for this club had 15 years' experience instructing students in developing science-fair projects, and his major was biology and environmental science. He received the national top 10 science teacher title in 2003 in China. His students received many awards, such as the Grand Awards in ISEF and special awards in CASTIC.

15.4.2 Data Collection and Tools

This research employed a case study design. Data were collected by semi-structured interview (Ou 2006) and document analysis (including club diary, research diary, science-fair schedule, and webpage discussion area).

We interviewed the teacher three times. We did the first and the second interview at the Winter Camp of Intel ISEF in China which took place in January 2007. In the first interview, we wanted to collect the teacher's learning experience and his motivation to guide students to develop science-fair projects. Sample questions included "Please describe your learning experience" and "What is your motivation for guiding students to develop science-fair projects?" In the second interview, we wanted to collect as much data as possible about the science club. Sample questions included "How did you arrange your time to guide the students?" and "How did you enable your students to learn the basic skills of scientific research?" We did the third interview during science teacher's training which was organized by the China Association for Science and Technology in March 2007. In the last interview, we wanted to collect information on the teacher's professional development. Sample questions were “Where did you obtain your knowledge of guidance?” and “How did you improve your ability to guide?”

We also collected the documents of the science club in the third interview. The club diaries included materials of the science club basic curriculum which were developed by the case teacher, discussions between students and the teacher, meetings of the science club, and students’ feelings about science research. We collected part of the club diaries which were recorded from January 2006 to January 2007.

The research diaries included the progression of students’ research projects, such as research questions, methods, and results. The research diaries also record the students’ difficulties in their research, the teacher’s guidance, and the student researchers’ discussions. We collected research diaries of ten students’ projects completed from January 2006 to January 2007.

The science-fair schedule included nearly all the information of science fairs in China. The webpage discussion area included all the research papers of the students’ projects in the science club and the progression of students’ projects. We collected ten students’ research papers and the progressions of ten students’ projects which were completed from January 2006 to January 2007.

15.4.3 Data Analysis

Firstly, the documents collected by semi-structured interviews were sorted out and analyzed by induction analysis. In order to improve the validity of the context analysis, the results were returned to the case teacher for rechecking.

Secondly, the documents of science club were analyzed by coding, using the framework developed by Collins et al. (1989) for designing an ideal learning environment from cognitive apprenticeship perspectives. We coded the methods the teacher used to guide the students in science fair. We used MO as the code name for modeling, CO as the code name for coaching, SF as the code name for scaffolding, AR as the code name for articulation, RE as the code name for reflection, EX as the code name for exploration, and OT as the code name for other methods. For example, according to the Collins et al (1989) definition of modeling, we selected the modeling content from the documents of the science club and marked them with MO. We then sorted out and analyzed all MO units to conclude the methods. In order to improve reliability and validity, two people from the research group selected the coding content and marked independently. Table 15.1 below lists the coding table of teaching methods.

Table 15.1 The coding table of teaching methods

Coding category	Definition	Examples	Source
MO modeling	1. Operating the experimental instruments	1. Before you do the experiment, you should learn how to use the instruments	Club diaries
	2. Showing how to use the statistical software	2. You can do it according to . . .	Research diaries
	3. Showing how to write the paper		Science-fair schedule
			Webpage discussion
CO coaching	1. Coaching students for writing papers	1. Students learn how to write a paper from teachers	Club diaries
	2. Providing opportunities of presentation for students	2. We will hold a seminar, please prepare . . .	Research diaries
	3. Giving guidance and suggestions for students doing science projects		Science-fair schedule
			Webpage discussion
SF scaffolding	1. Providing strategies for students to help them find ideas	1. You can find ideas from observing	Club diaries
	2. Building an expert system for giving students support	2. If you need consulting, you can find experts from our experts system	Research diaries
	3. Proving awarded project papers for students		Science-fair schedule
			Webpage discussion
AR articulation	1. Students upload the research progression to the webpage	1. Please elaborate your progression of projects	Club diaries
	2. Students keep a research diary	2. Do the results from fieldtrips match the experiments?	Research diaries
			Science-fair schedule
			Webpage discussion
RE reflection	1. Students compare their research with teacher's research	Is there any difference between your method and other projects?	Club diaries
	2. Students communicate ideas with experts		Research diaries
	3. Students compare their research with awarded projects		Science-fair schedule
			Webpage discussion

(continued)

Table 15.1 (continued)

Coding category	Definition	Examples	Source
EX exploration	1. Push students into the problem-solving model	With so many materials, you can think . . .	Club diaries
	2. Encourage students build their own research process		Research diaries
			Science-fair schedule
			Webpage discussion
OT other	1. Give encouragement	You really did a great job!	Club diaries
	2. Arrange schedule		Research diaries
			Science-fair schedule
			Webpage discussion

15.5 Results

15.5.1 Content

Content includes four parts: domain knowledge, heuristics strategies, control strategies, and learning strategies. Domain knowledge includes the conceptual and factual knowledge and procedures explicitly identified with a particular subject matter. These are generally expounded in school textbooks, class lectures, and demonstrations (Collins et al. 1989). In science clubs, the activities undertaken are mainly projects, which differ from the demonstrations in conventional classes. In the science club of this case study, the teacher used a variety of activities to encourage student domain knowledge learning. These activities were core course, research projects, making a science club website, training new science club members, and various community activities.

- The teacher developed a core course to nurture students' basic scientific research skills, designed many activities, and enriched cases and classroom lectures to help students learn and understand basic scientific research skills.
- After students completed the core course, they began to carry out science research projects engaging in a set of research activities. Students selected topics independently and then formed teams according to their interests. Each team was required to report their progress to the teacher at a specific stage and to maintain

a research diary. The teacher encouraged students to make full use of the resources in their school, especially lab resources. During the research project work, the teacher and students formed a learning community and discussed their experiences and ideas in the science club.

- The teacher organized students to collaborate with a technology company to make a website for the "Biology and the Environment Science Club" (the name of the science club; www.bioenv.com). Students were responsible for updating the science club's website including uploading many research project cases providing references for students interested in scientific research.
- New members became familiar with the systems and rules of the science club, so the teacher arranged training for them to help them participate.
- The teacher also used a variety of activities within the communities where students live which served as a special teaching strategy. Combining student projects with communities encouraged students to pay more attention to the environment in which they live and cultivated their ability to apply problem-solving skills in real life. The situated cognition and learning theory emphasizes the creation of learning environments that particularly involve real situations and meaningful activities and the provision of opportunities for understanding and experiencing interactions. The teacher organized the students to participate and engage in community activities consistent with the situated learning theory. This teaching strategy was a win-win solution: many students' projects involved community activities, and the students' research, in turn, improved the communities' environments.
- The natural environment was the best resource for students to carry out research, so the teacher arranged appropriate field observations for students. Because of safety and cost considerations, the places selected for field observations were near the school and students' homes.

The analysis above demonstrates that the teacher used a variety of activities for students to learn and understand domain knowledge. Table 15.2 below lists the type of domain knowledge students can learn from each activity.

Heuristic strategies are generally effective techniques and approaches that teachers use to guide students to accomplish tasks. Heuristic strategies enable students to make inferences from one case to another, thereby effectively obtaining

Table 15.2 Science club teaching activities and domain knowledge

Science club's teaching activities	Domain knowledge
Core course	Conceptual, factual, and procedural
Research projects	Conceptual, factual, and procedural
Making a science club website	Conceptual, factual, and procedural
Training new science club members	Factual and procedural
Activities in the community	Conceptual, factual, and procedural
Field observation	Conceptual, factual, and procedural

twice the result with half the effort (Collins et al. 1989). The teacher in the case study used two heuristic strategies: the first was encouraging student researchers to take part in science competitions in order to improve their ability to conduct scientific research. For both the students and their teacher, science competitions provided a good opportunity to communicate with other competitors and thus gain more experience. The teacher often organized students to participate in CASTIC, Junior Scientist, ISEF, and other science competitions. The second strategy was encouraging students to participate in science competitions at all levels. Entering students into these different levels helped students reflect upon and revise their science projects.

As the name suggests, control strategies control the process of carrying out a task. The teacher in the study used some of these to manage the students in the science club.

- The teacher used science club regulations, which were discussed and endorsed by all science club members, to manage the students. The teacher also tried to create a science club culture of enthusiasm for science and protecting the environment as another way to guide the students.
- Each research team kept a research diary, recording when, where, and how the team members accomplished their scientific research. Students were trained to use self-reflection and self-direction.
- Students were responsible for updating and maintaining the science club's website. Each research team uploaded their research data and results onto this website. This information also provided a good opportunity for students to reflect upon their research. The science club website also had an evaluation system which could track the progress of students' research. When they met with a difficulty or experienced a problem, experts online could give them support.
- Science club members could also discuss problems with their teacher or other experts in the science club. These spontaneous meetings between students and their teacher often encouraged students to continue with their research.

Learning strategies promote any of the content described above, i.e., domain knowledge, heuristic strategies, and control strategies. The students performed their research in groups and selected their own team leader. They worked cooperatively, and in the science club, various activities provided enabled them to improve their abilities. Besides the core course and the research course, the teacher also created other opportunities for students to learn research skills. Students could contact experts for advice when needed. The science club website was also an important place for students to communicate and learn.

These strategies provided full digital and actual learning environments to strengthen students' motivation for learning and improved students' ability to learn domain knowledge, heuristic strategies, and control strategies.

15.5.2 Methods

The teaching methods were designed to give students the opportunity to observe, engage in, invent, or discover new findings (Collins et al. 1989). In Collins et al.'s (1989) theory, teaching methods include modeling, coaching, scaffolding, articulation, reflection, and exploration. We analyzed the teacher's interview data and the science club's materials and summarized the teaching methods of the teacher as follows.

Modeling involves showing an expert carrying out a task so that students can observe and build a conceptual model of the processes that are required to accomplish the task. In cognitive domains, this requires the externalization of usually internal processes and activities, specifically, the heuristics and control processes by which experts make use of basic conceptual and procedural knowledge (Collins et al. 1989). The teacher in the study used four methods: modeling the operation of experimental equipment, modeling the use of statistical software, modeling the writing of a research article, and modeling the research strategies.

Coaching consists of observing students while they carry out a task and offering advice or providing them with scaffolding, feedback, modeling, and/or reminders, which will help them master new tasks and bring their performance closer to that of an expert (Collins et al. 1989). Coaching focuses on the enactment and integration of skills in the service of a well-understood goal through highly interactive and highly situated feedback and suggestions. For the case study teacher, the coaching method was requiring students to summarize published papers: in the core course, students summarized at least ten papers. The teacher used this strategy to train the students to write research articles, providing an opportunity for students to practice an oral presentation and exhibit a project; he also regularly monitored the science club website so that he could give the best advice to each team about their research project.

Scaffolding refers to the support the teacher provides to help a student carry out a task. Fading consists of the gradual removal of this support until students can work independently. The teacher in this case study used the following scaffolding methods:

- Framing a research question at the start of research. Students often met difficulties in framing a research question when starting a research project. The teacher in the study taught students "five-W questioning" to help them improve their ability to formulate good research questions.
- Establishment of an expert support system. The teacher enlisted the assistance of several responsible and highly motivated professors who helped his students with their research projects and promoted their research abilities. He then encouraged his students to contact these experts for support and guidance and modeled how they should do this.
- Provision of research samples. The teacher provided students with some award-winning research papers and diaries from CASTIC and ISEF, anticipating that

they would benefit from comparing their research project to these award-winning papers.

Articulation includes any methods to help students voice their knowledge, reasoning, or problem-solving processes in a domain (Collins et al. 1989). There were several methods of articulation that this case study teacher used. The first involved evaluating the progression of students' research through the information they had loaded onto the science club website, such as their research hypotheses, research designs, and final research reports. The second involved students who keep writing research diaries in order to practice their writing skills. These strategies enabled students to express or articulate their knowledge and improve their writing skills.

Reflection (Brown 1985a, b) involves enabling students to compare their own problem-solving processes with those of experts, other students, and, ultimately, an internal cognitive model of expertise. Reflection is enhanced by the use of techniques for reproducing or replaying the performance of both expert and novice for comparison. Through reflection, the learner can question themselves. In the science club, each research group had two teachers, one from the middle school and the other from the expert support system. The experts helped the young researchers solve challenges, thereby cultivating their abilities through this interaction. Comparing their work with award-winning research projects provided another way for them to reflect upon their endeavors and refine their science projects.

Exploration involves pushing students into a mode of problems solving independently. Encouraging students to explore is critical so students learn how to frame interesting questions or problems that they ultimately can solve. As part of science project guidance, exploration as a method of teaching involves helping students frame a question. Before framing the question, the "five-W questioning" method was taught to the students. The teacher also promoted research exploration among the students by scheduling meeting times and stating exactly when CASTIC was to be held. Students would therefore work hard to complete the research on time.

In conclusion, the case study teacher used operational strategies to help his students learn science process skills. In particular, he used the strategies of modeling, coaching, scaffolding, articulation, reflection, and exploration.

15.5.3 Sequence

Collins et al. (1989) thought that in an ideal learning environment, students would develop their skills better if learning was structured in a particular way: from simple to complex with increasing diversity and from global to local skills. The chief effect of this sequencing principle is to allow students to build a conceptual map before attending to the details of the terrain. The case study teacher arranged the learning activities of the science club in the following way (Fig. 15.1).

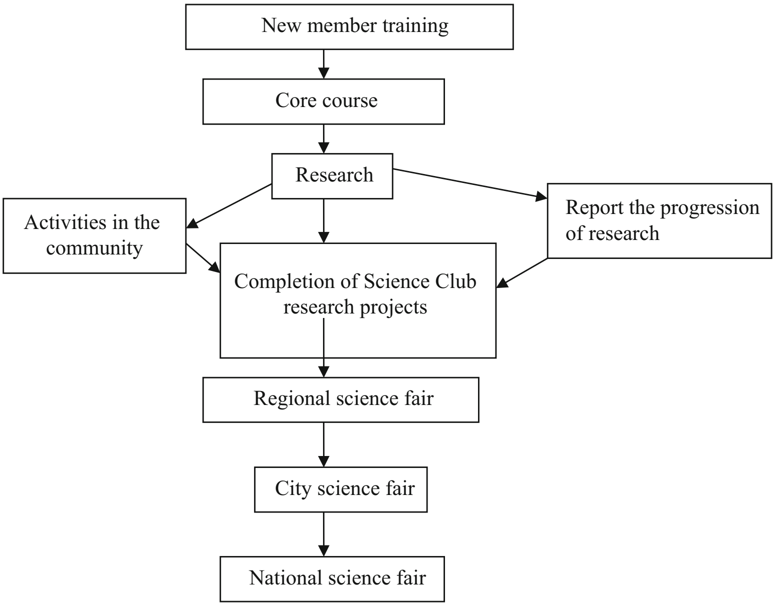

Fig. 15.1 The sequence of learning activities in science club

15.5.4 Sociology

The final dimension in Collins et al.'s (1989) framework is sociology of the learning environment—a critical dimension often ignored in making decisions about curriculum and pedagogical practice. The sociology in the science club is as follows:

A critical element for learning was that students were carrying out tasks and solving problems in an environment that reflected the multiple ways their knowledge would be put to use in the future. In the science club, the case study teacher created numerous activities enabling students to understand and apply their knowledge.

Community of practice refers to the creation of a learning environment in which participants actively communicate about and engage in the skills involved in expertise, where expertise is understood as the practice of solving problems and carrying out tasks in a domain. Completion of research projects can develop students' science process skills. The case study teacher established an expert support system for the science club and encouraged the students to communicate with experts. These strategies prompted students' research and constructed a learning environment and community of practice.

Related to the issue of situated learning and the creation of community of practice is the need to promote intrinsic motivation for learning. Malone (1981) discussed the importance of creating a learning environment in which students perform tasks because they are intrinsically related to an interesting or at least coherent goal, rather than for some extrinsic reason like getting a good grade or pleasing the teacher. The case study teacher strengthened students' intrinsic motivation through these strategies. First, the case study teacher modeled good practice by undertaking the research himself, providing a good example for the students. Second, the case study teacher created a positive culture within the science club to motivate his students. These two strategies motivated students to complete the research because they loved science and not because of parental or teacher pressure. This intrinsic motivation prompted students to overcome the difficulties in research.

Students formed groups according to research direction. In groups, students cooperated to make progress on and complete the research; they helped and learned from each other. The science club also promoted competitive environment by creating a research project competition where groups would vie with each other in order to make progress on their research and achieve better outcomes.

15.6 Discussion/Conclusions

In summary, the case study highlighted the teaching strategies that an award-winning teacher used to help students develop research projects in the context of a science club. The case study teacher designed various activities to organize students into research groups. Based on situated cognition and learning theory, the science club constructed a sociological environment in a science community. The interaction among students, teachers, and experts improved the effects of learning.

In China, students do not have much time to develop science projects because of study pressure, so most students do their science projects in their spare time. Because of a shortage of science project teachers, most students do not participate in science fairs. It is important to organize students to develop science projects using science club model which can cater to and guide more students simultaneously. Science clubs have advantages in terms of organizing students because all members are linked by a common interest in science and research. Science clubs have clearly stated regulations discussed and endorsed by all science club members. The cooperative and competitive environment in science clubs also motivates students to complete research to the best of their abilities.

Most science-fair projects come from science club sand are team projects, which is a typical characteristic of the science club model. The cooperative structure has shown to be preferred in inquiry learning (Tjosvold et al. 1977), promote positive attitudes (Humphreys et al. 1982), and be the most effective structure for the majority of students when paired with competition (Okebukola and Ogunniyi 1984). It also has been shown that the individualistic structure is very effective in competitions, especially for highly capable students (Michaels 1977). The individualistic structure may also be desirable if one of the goals of the school science fair is to select a winner to progress to another competition that accepts only individual efforts. Since the cooperative structure is the most effective for the majority of students, the science club model is useful for most schools to nurture students developing science-fair projects. Although the science club model can help students finish science projects, the key to the science club model is in the design of content and activities and the use of teaching strategies. The case study teacher designed a core course, instituted various activities, and used effective strategies to encourage students in their research.

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