Asian Journal of Biology Education, 2013
https://doi.org/10.57443/ajbe.7.0_12

Research Paper

A Lab Guiding Tool for a Life Science Experiment that Possibly Provides Teachers' Tacit Knowledge: Evaluation of Its Efficacy for Auto-tutorial Support in Upper Secondary Schools

Hiroshi Okuda*
University of Tsukuba and Shibaura Institute of Technology Senior High School, Japan

(Received: 18 June 2013; accepted: 30 December 2013)

A lab guiding tool that provides teachers' tacit knowledge was developed to outline the procedure of a life science experiment, and its effectiveness was examined. At first, some lab instructions and teaching plans that had been already published were collected for an analysis of the actual state of teaching practices. It was founded that (1) these lab instructions focused on experimental procedures and did not contain the knack that teachers accumulate from their experiences (tacit knowledge) and (2) an environment supporting students in reconfirming teacher's instructions had not been established. The author thus analyzed teachers' tacit knowledge required for students' practice on "Making preparations for microscopic observation." The author made said knowledge into a transmittable form by using numeric representation and images, assembled it into a new instructional tool (a lab guiding tool), and developed a learning environment in which students can reconfirm the instructions. The new lab guiding tool improved the success rate and reduced the number of discarded specimens. The high success rate could be attributed to good ideas generated by the information that students had obtained from the new lab guiding tool. The reduction in the number of discarded specimens was due to less wasted motion and students' failure in performance.
Key words: lab instructions, lab guiding tool, life science experiment, teachers' tacit knowledge
* Shibaura Institute of Technology Senior High School, Kashiwa-shi, Chiba 277-0033, Japan.
E-mail: okudahi@ka.shibaura-it.ac.jp

INTRODUCTION

The new Courses of Study notified by Ministry of Education, Culture, Sports, Science and Technology, Japan (MEXT) claimed the enrichment of observations, experiments, and scientific experiences (MEXT 2011a, 2011b). However, some investigations of science education in upper secondary schools revealed that many Japanese teachers had performed teacher-led experiments, not student-led ones; that is, "The students only follow the prescribed experimental procedures" (MEXT 1999, Central Council for Education 2004, Japan Science and Technology Agency 2010).

Therefore, students, being inexperienced, might obtain unsatisfactory results in the experiments if they followed only the prescribed experimental procedures. For instance, "Observation of mitosis in onion root tip cells" is considered an important experiment in Japan because it has been described in all science and biology textbooks for a long time (Hatogai 2011, Tokyo Metropolitan School Personnel In-service Training Center 2005). However, teachers and researchers have pointed out some difficulties in performing this experiment and have tried to make it easier by developing methods with fewer steps. Even when the students used these easier methods, 10% – 15% of them failed in the preparation. The causes included "a cover glass slips out of place in the squashing step" and "squashing pressure is insufficient" (Kawakami and Kato 2004, Tokyo Metropolitan School Personnel In-service Training Center 2005, Nakatake and Nakayama 2006, Yonezawa *et al*. 2006).

This is partly because the squashing step requires a knack for applying an appropriate degree of pressure on the specimen with one's thumb, which depends on each specimen. At present, the author thinks that students have little chance to obtain their teachers' tacit knowledge[1)] since teachers has accumulated the tacit knowledge, such as the knack which is hard to be described, from their experiences.

It has been reported that even when teachers perform demonstrations involving the knack, students will fail to learn from an event when exposed to it only once (Sweller 1988, Taylor 1988, Chandler and Sweller 1991, Majerich and Schmuckler 2008).

Therefore, a success or failure of a life science experiment depends on various factors, such as differences in the individual experimental specimen and certain steps in the experiment that need tacit knowledge. According to some reports on Asian higher education reported that tacit knowledge played a vital role in scientific research and education (e.g., Zhang and Han 2008, Hara *et al*. 2010). Furthermore, some Japanese reports have indicated that tacit knowledge is important to promote the understanding and use of scientific knowledge (Central Council for Education 2006, 2008). However, the role of tacit knowledge in science experiments in Japanese secondary education has not been sufficiently researched. Therefore, this study focused on transmitting the teachers' tacit knowledge to students by improving conventional lab instructions that described the experimental procedures. If students were provided with the teachers' tacit knowledge in the lab instruction, their experiment results (e.g., success rate and the length of operation time) would be improved.

In *Study I,* an experiment, "Observation of mitosis in onion root tip cells" was chosen to analyze the instructions of experiments in school textbooks and teaching plans. In *Study II,* a new lab instructional tool that could provide the teachers' tacit knowledge was developed and examined its effect on students' lab practice.

[STUDY I]
ANALYSIS OF THE ACTUAL STATE OF INSTRUCTIONS OF EXPERIMENTS

Study purpose

The lab instructions on "Observation of mitosis in onion root tip cells" in Japanese science and biology textbooks and the teaching plans for this experiment were collected to analyze the descriptions of experimental procedures to identify problems in carrying out the experiment.

Methods

Analysis of descriptions in lab instructions

Lab instructions on "Observation of mitosis in onion root tip cells" in six Japanese science textbooks for lower secondary school students and four biology textbooks for upper secondary school students were assessed regarding explicit knowledge[2)] in the descriptions of five steps of the experiment: fixation, maceration, washing, staining and squashing, and teachers' tacit knowledge particularly knacks about the step of squashing of tissue.

Analysis of teaching plans

Eight teaching plans for "Observation of mitosis in onion root tip cells" were obtained from the websites of following municipal education centers until August 15, 2012: Tokyo, Niigata, Tochigi, Gifu (two plans), Ishikawa (two plans), and Kagoshima. Descriptions of the "Methods of Explanation" and "Guidance to Individuals," which instructed the teacher to visit each lab bench and to give guidance to individuals if necessary, in the eight teaching plans were analyzed.

Results

Analysis of lab instructions

Table 1 shows the explicit knowledge regarding five steps of the experiment, "Observation of mitosis in onion root tip cells." Table 2 shows the status of the descriptions of explicit knowledge required for each step mentioned in Table 1 and the indication of the method for squashing of tissue in the lab instructions in the ten textbooks. No lab instructions described most of the explicit knowledge, such as the aim of each operation and the action of the chemicals; only operation procedures were described.

Three lab instructions provided concrete descriptions of the direction of squashing, that is, vertical, by using simple illustrations. However, there were differences among these descriptions. The degree of pressure was indicated in some instructions as "gently," "slowly," or "strongly," but any reason for carrying out such action was not included though adjusting the pressure according to the conditions of specimens was required for spreading them well. Adequate instructions on how to squash and on the degree of pressure in the final preparatory step were not provided. Only three lab instructions mentioned the actions of chemicals briefly.

In short, all lab instructions examined did not sufficiently cover explicit knowledge; the details of the procedures were unclear and differed among the publishers. Furthermore, there was almost no description of the teachers' tacit knowledge that is the specific knack required for a particular step.

Table 1 Explicit knowledge of five steps in the experiment, "Observation of mitosis in onion root tip cells"

step	Explicit knowledge of five steps
Fixation	Fixatives (acetic acid, ethanol, etc.) can preserve biological structures such as cells and tissues as close to their natural state as possible.
Maceration	The maceration solution (dilute hydrochloric acid) can separate cells from one another easily. Excessive maceration can break cells and inhibit staining. Insufficient maceration leaves cells intact, that is, hard; therefore, cells cannot be spread into a layer even if squashed.
Washing	The washing solution (water) can remove the fixatives and maceration solution, both of which may inhibit staining. Excessive washing hardens a sample. Insufficient washing causes insufficient removal and staining.
Staining	The staining solution (acetocarmine, etc.) can stain nuclei and chromosomes reddish purple. Excessive staining hardens a sample. Insufficient staining makes observation difficult because of the poor contrast.
Squashing	By squashing, cells are spread into a layer and can be easily observed under a microscope. Excessive squashing can break cells. Insufficient squashing makes observation difficult because the overlap of the cells is maintained. Non-vertical squashing causes a shearing deformation of tissues and the resultant cell destruction and chromosome breakage.

Table 2 Descriptions of explicit knowledge required for five steps and indication of squashing in the lab instructions in 10 textbooks

Lab instruction*		Descriptions of explicit knowledge required for five steps **					Indication of squashing
		FX	MA	WA	ST	SQ	
1	KR (JHS)	○	△	×	△	×	Concrete indication of "vertical" for the direction of squashing
2	GA (JHS)	×	△	×	×	×	
3	DG (HS)	×	×	×	×	×	Not indicated concretely
4	JS (HS)						
5	KR (HS)	○	△	×	×	△	
6	TS (HS)	×	×	×	×	△	
7	KS (JHS)	×	△	×	×	×	
8	DN (JHS)						
9	TS (JHS)						
10	SS (HS)						

*** Japanese school textbook publishers (Abbreviation)**
KR: Shinko Shuppansha Keirinkan Co., Ltd.; GA: Gakko Tosho Co., Ltd.; DG: Daiichi Gakushusha Corporation; JS: Jikkyo Shuppan Co., Ltd.; TS: Tokyo Shoseki Co., Ltd., KS: Kyoiku-shuppan. Co., Ltd.; DN: Dainippon Tosho Publishing Co., Ltd.; SS: Suken Shuppan Co., Ltd.
**** Experimental steps**
Abbreviations FX: fixation; MA: maceration; WA: washing; ST: staining; SQ: squashing
Marks ○: Described; △: Described a part; ×: Not described

Analysis of teaching plans

Four plans described the "Methods of Explanation" as a combination of oral explanation with showing slides and demonstrations before students' experiments. Three teaching plans mentioned "Guidance to Individuals" by the teacher during the experiment. From these teaching plans, it appears that students are expected to follow the procedure according to the teacher's instructions and cannot have enough opportunity to ask the teacher about his instructions after he has finished them, even if the instructions included the teachers' tacit knowledge.

[STUDY II]
DEVELOPMENT OF A LAB INSTRUCTION AND VERIFICATION OF ITS EFFICACY FOR AUTO-TUTORIAL SUPPORT

Study purpose

On the basis of the results of *Study I*, a plan was formulated to develop a new lab instruction, in which the following ideas were reflected: (1) to make the teachers' tacit knowledge, which is difficult to verbalize, a transmittable form by using illustrations and images (still pictures and movies); and (2) to develop a learning environment in which students can reconfirm the teacher's instructions. Then the usefulness of the new lab instruction on performing the students' laboratory was verified in an upper secondary school.

Methods

Setting of a task

As "Observation of mitosis in onion root tip cells" is widely practiced in lower secondary schools, "Making a preparation of salivary gland of a Chironomidae larva for the observation of giant chromosomes" was selected, because that is only described in upper secondary school textbooks. The other reasons for the selection are (1) the practice has been described for a long time in Japanese upper secondary school textbooks; (2) individual differences exist among living insects; (3) it seems difficult for students to achieve this task by only following written experimental procedures, so the teachers' tacit knowledge may be required; and (4) the time required to complete this task is relatively short.

The experimental procedures of this task were as follows: introduction (explanation of the specimen, apparatus, and chemicals), operation step 1 (OP1: setting a specimen on a slide glass), operation step 2 (OP2: separation of the larva's head from its body), operation step 3-1 (OP3-1: removing entrails, including salivary gland, from the body), operation step 3-2 (OP3-2: separation of salivary gland from entrails), and operation step 4 (OP4: staining the salivary gland).

Development of a lab instructional tool

In order to develop the lab instructional tool, the author (1) performed a preliminary implementation of the task to identify particular steps for which teachers' tacit knowledge is useful and (2) made such teachers' tacit knowledge into transmittable forms and packed them into the lab instructional tool.

The author conducted the preliminary implementation for 11 first-year students of an upper secondary school who were divided into the control and experimental groups. A print that contained the experimental procedures and some still pictures was made as the preliminary lab instructional tool. In addition to the print, movies that showed mainly the operation procedures were provided to the students in the experimental group; they could watch the movies by a notebook PC. The students of the both groups were asked to perform all the operations of this task by themselves and to submit three complete preparations. The author judged the success or failure of the submitted preparations by microscopic observation; those without salivary gland or with salivary gland plus other organs or tissues were regarded as failures. The ratios of successful preparations to the total in the control and experimental groups were examined for the difference between the two groups. As a result, there was no significant difference in the ratio between the two groups. This suggested that the movies could not have any effect on the students' performance; these movies might not include sufficient teachers' tacit knowledge. Thus, a questionnaire survey of all the attending students regarding the degree of difficulty of the experimental procedures was conducted. Six students answered OP3-2 and three students answered OP2 as the most difficult procedure.

As stated above, it was hardly possible to express the teachers' tacit knowledge by only recording their operation. So, the author try to analyze the teachers' tacit knowledge for some steps, especially OP2 and OP3-2, referring to a method called "Skill Analysis Methods for Training" (Mori 2005) which had been introduced in industrial circles. This method indicates the following: (1) all the operations by an expert teacher, who has the tacit knowledge on such life science experiments, are recorded on video, (2) while watching the recorded performance together, his tacit knowledge is possibly extracted by an interview, and then (3) his tacit knowledge is expressed by using numeric representation and images. Interviewing has been considered to be very effective in accessing teacher's practical knowledge, which is often tacit and implicit, because they do not incline to articulate their practical knowledge (Meijer *et al*. 1999, Zanting *et al*. 2003). Interviewing may be effective to extract the specific knack for a particular step in life science experiments. Thus, in this study, the author tried to extract the teachers' tacit knowledge by interviewing. Then, by using the above method, the author made the teachers' tacit knowledge into transmittable forms, such as shown in Figure 1, and assembled them into a lab guiding tool, as shown in Figures

2. Figure 1 shows a still picture that shows the proper angles between the razor blade and specimen and the forceps and specimen. Figure 2 shows a part of the new lab guiding tool, which contains the experimental procedures, some still pictures, and a built-in movie on OP3-2. This part shows how to identify salivary gland for separating it from the entrails, based on the fact that salivary gland is transparent, while the rest (e.g., entrails) is translucent or opaque.

The new lab guiding tool was developed for use on a tablet PC, because the tablet PC is easy to use in playing back images, has good operabilities, and occupies a minimal space on the lab bench.

The subject of study

Sixty-seven second-year students of an upper secondary school were involved in the implementation of the new lab guiding tool. The subject students were divided into two groups: a control group and an experimental group. The similarity of the subject students in the control and experimental groups was given careful consideration. The 35 students in the control group were divided into five subgroups and the 32 students in the experimental group into four.

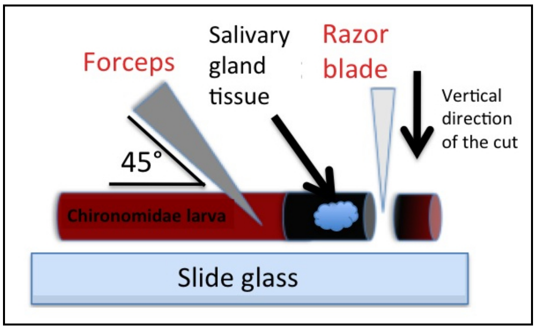

Figure 1 The still picture of operation step 2

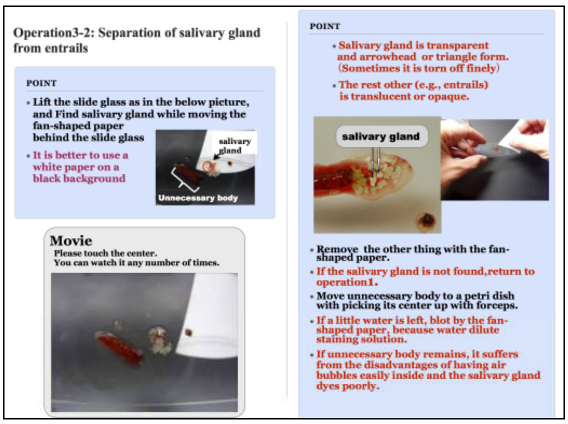

Figure 2 The instructions of operation step 3-2 in the new lab guiding tool

The students in the control group used an ordinary lab instruction, a print, which had been used for this student lab so far. The print contained the experimental procedures and some still pictures. The students in the experimental group used the new lab guiding tool.

Verification process

The following factors were investigated to verify the benefits of the new lab guiding tool on learning: (1) the number of successful students, (2) the time required to complete the whole task ("Total time"), (3) the time required to read or watch the lab instruction or the new lab guiding tool ("Manual time"), (4) the time required to complete the whole operation steps ("Operation time"), and (5) the number of discarded specimens.

The verification process is as follows: the students all seated and started the experiment simultaneously. The availability of apparatus (e.g., the number of forceps) was the same in the control and experimental groups. Though the both groups performed the task in the same room, any conversation and the exchange of information between them were forbidden. The students were asked to declare the completion of the whole task. Each of the students could use specimens up to 10 and had to submit three complete preparations. They performed all operations by themselves. Teachers did not answer any question concerning the operations for preparation.

The time needed to complete the whole task had been estimated 30 minutes. The operations performed by each student were recorded by video cameras. The time required for the operations was measured with stopwatches. The video recordings could provide such data as the number of times the movies were viewed and the number of specimens used by each student.

The preparations that were submitted by each student were numbered from 1 to 3 (1st Preparation, 2nd Preparation, and 3rd Preparation), in the order of submission. For each submission, teachers examined whether the preparation was successful. At the end of the class, both submitted and discarded specimens were counted.

Results

The students, whose full operations could not be recorded on video, who abandoned the experiment, who used more than 10 specimens, who were unable to submit three preparations, or who did not follow the instructions, were dropped from the roster. As a result, the number of students in the two groups went down to both 28.

Comparison of the number of successful preparations

Table 3 shows a comparison of the number of successful preparations between the two groups. The number of successful preparations was larger in the experimental group than in the control group, i.e., the chi-square test (df = 1) for the difference in the number of successful preparations showed the existence of a significant difference ($p < 0.01$) between the two groups.

Table 3 Comparison of the number of successful preparations

	Number of submitted preparations	Number of successful preparations	SD
Control group (N=28)	84	28	**
Experimental group (N=28)	84	47	

** $P < 0.01$

Comparison of the number of successful students

Figure 3 presents a comparison of the number of successful students on each submission of preparation. Significant differences between the control group and the experimental group were observed in the number of successful students of the 2nd Preparation ($p < 0.05$) and the 3rd Preparation ($p < 0.01$). This result indicates that the new lab guiding tool used by the experimental group increased the proportion of successful students.

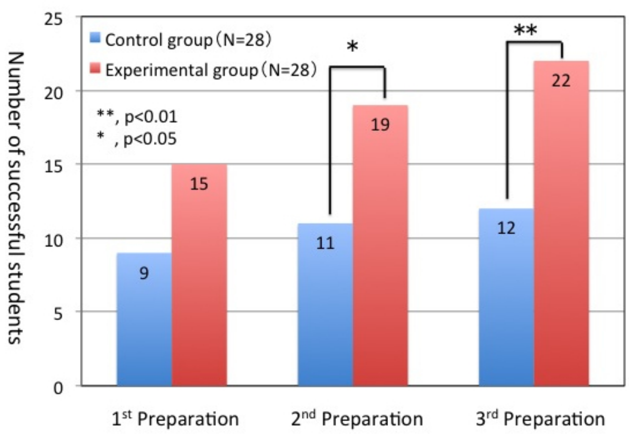

Figure 3 Comparison of the number of successful students

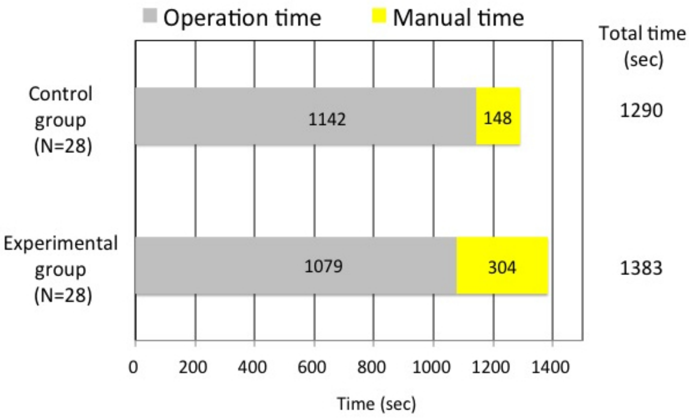

Figure 4 Comparison of the "Total time" of the two groups

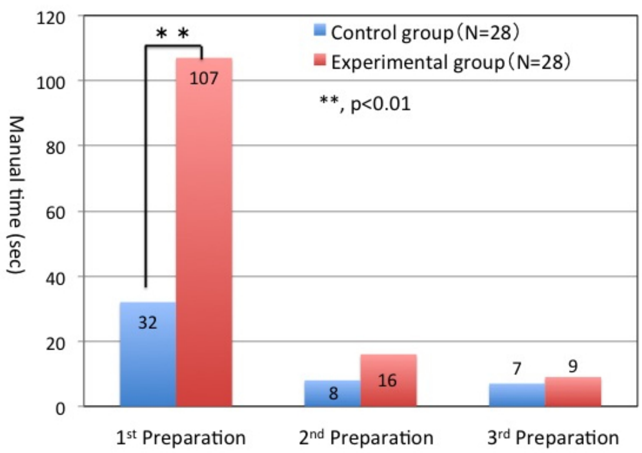

Figure 5 Changes in the "Manual time" of the two groups

Comparison of the "Total time"

The "Total time", "Manual time" and "Operation time" of the both groups were compared (Figure 4). The Mann-Whitney test for the "Total time" between the two groups (1290 sec and 1383 sec) did not show a significant difference. On the other hand, the chi-square test (df = 1) for the difference in the ratio of "Manual time" to "Operation time" between the two groups showed the existence of a significant difference ($p < 0.01$).

Changes in "Manual time"

The "Manual time" for completing each preparation was measured, averaged, and used in the subsequent analysis (Figure 5).

This result indicates that the "Manual time" decreased in the two groups as the experiment progressed. The Mann-Whitney test for the "Manual time" between the two groups yielded a significant difference ($p < 0.01$) for the 1st Preparation (32 sec and 107 sec). In the early steps, "Manual time" was much longer in the experimental group than in the control group. However, no significant difference between the two groups came to exist as the experiment progressed. This may mean that it took time for the students in the experimental group at first to select the requisite information from the lab guiding tool because they had a difficulty in determining which information was relevant to the task in dealing with and important in completing the task.

Changes in "Operation time"

The "Operation time" for each submitted preparation in the two groups was measured, averaged, and used in the subsequent analysis (Figure 6). The "Operation time" for the 1st Preparation in the experimental group (249 sec) was longer than that in the control group (185 sec). The Mann-Whitney test revealed that the difference (between the two groups) was significant ($p < 0.01$). As the experiment progressed, the "Operation time" in the control group did not get shorter markedly (the 1st Preparation: 185 sec; the 3rd Preparation: 181 sec), while that in the experimental group seemed to decrease apparently (the 1st Preparation: 249 sec; the 3rd Preparation: 185 sec). The Wilcoxon test for the "Operation time" between the 1st Preparation (249 sec) and the 3rd Preparation (185 sec) in the experimental group showed the existence of a significant difference ($p < 0.01$). This indicates that there was a difference in the "Operation time" of the two groups only in the early stage of the experiment.

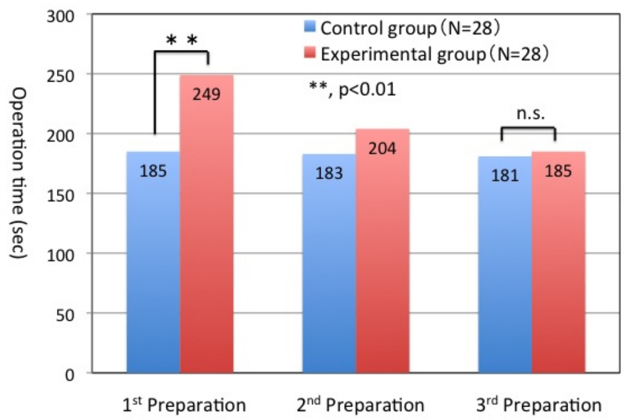

Figure 6 Changes in the "Operation time" of the two groups

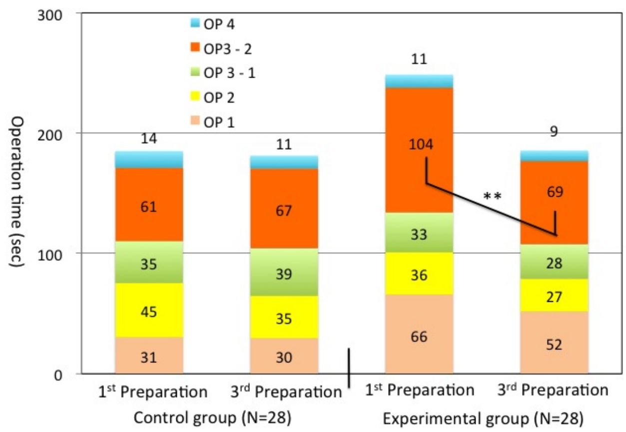

Figure 7 Comparison of the time required for each operation step

In order to clarify the reason for the difference in the "Operation time" in the early stage, the author compared the duration of each operation (from OP1 to OP4) required for submitting the 1st Preparation and the 3rd Preparation of the both groups (Figure 7). The Wilcoxon test was performed to examine the difference in the time of the two groups. There was a significant difference (at the 1% significance level) in the time required for OP3-2 between the 1st Preparation and the 3rd Preparation in the experimental group. The time required for OP3-2, "Separation of salivary gland from entrails," decreased in the experimental group as the experiment progressed. This result indicates that through viewing of the movies the students obtained teachers' tacit knowledge needed for the separation of salivary gland.

Table 4 Comparison of the number of discarded specimens

	Number of discarded specimens	SD
Control group (N=28)	116	**
Experimental group (N=28)	62	

** P < 0.01

Comparison of the number of discarded specimens

Table 4 shows a comparison of the number of discarded specimens between the two groups. The number of discarded specimens was less in the experimental group, and the chi-square test (df = 1) showed the difference was significant ($p < 0.01$). The result indicates that the lab guiding tool used by the experimental group might contribute to the reduction in the number of discarded specimens.

GENERAL DISCUSSION

By analyzing the descriptions of "Observation of mitosis in onion root tip cells" in textbooks and teaching plans in *Study I,* it was confirmed that experiments conducted in lower and upper secondary school science classes in Japan were teacher-led, and the lab instructions that had been used focused on the explanation of experimental procedures and included almost no tacit knowledge, such as knack. Teachers' knowledge is tacit rather than explicit, and personal rather than collective (Robertson 2005). Moreover, the teachers, who have tacit knowledge, are apt to protect their intellectual property (Zhang 2008). It may be difficult for such teachers to realize the significance of their tacit knowledge and to turn it into explicit knowledge by themselves, because these teachers often perform their instructions without any consciousness.

As a result of this analysis, it appeared that an environment supporting students in reconfirming the teacher's instructions had not been established. With the development of information technology and computers, interactive movies that are watched on PCs can provide students with support for their deeper comprehension, because students can review the important information that they have missed (Merkt and Schwan 2013, 2014). Movies can be one of the valuable sources of information for students in biology education (Smith and Reiser 2005). But as a result of the author's preliminary implementation, it was confirmed that the movies in which mainly the operation procedures were shown could not have any effects on the students' performance; these images might not include sufficient teachers' tacit knowledge even if students could reconfirm the movies. The results revealed that the teachers' tacit knowledge was hardly possible to transfer to students by only showing their operations in life science experiments that required the specific knack.

The lab guiding tool developed in *Study II* possibly provided the teachers' tacit knowledge to students, because it improved the success rate and reduced the number of discarded specimens. The high success rate in the experimental group was due to good ideas generated on the basis of information that students had obtained by reconfirming the images that included the teachers' tacit knowledge. In addition, the reduction in the number of discarded specimens was due to the decrease in both the waste of motion and the failure in student performance. These results reveal that, for improving the students' performance in life science experiments, it needs not only to assemble the still pictures and movies into a lab instructional tool, but also to combine it with teachers' tacit knowledge extracted by interviewing.

It is found that the lab guiding tool required more time for reading the print, looking at still pictures, and watching movies in the early trials, so that it did not decrease the "Total time". However, this result can be interpreted as showing that the students were not busy with the operations, but instead performed the task by thinking by themselves with referring to the lab guiding tool. Their efforts toward the acquisition of teachers' tacit knowledge bore fruit in the latter trials, so that the "Total time" of two groups was almost the same.

CONCLUSIONS

The author can conclude that if students would be given a lab guiding tool that possibly provided them with the teachers' tacit knowledge, they could perform their experiment better.

The essence of science education is to foster the capability of students to develop an interest in natural phenomena and pursue them scientifically through their own successful experiences in experiments. This entails the learning of the methods of scientific inquiry. Thanks to the lab guiding tool that provides teachers' tacit knowledge, a further step can be taken toward such ideal education. In other studies, the author will examine the functions of the lab guiding tool in life science education, the methods of enhancing and maintaining students' interest in experiments, and the functions of a tablet PC and moving pictures required for the lab guiding tool.

Acknowledgements

The author thanks Prof. Kazuo Watanabe (University of Tsukuba), Dr. Kazuo Mori (Laboratory of Skill & Technology Education), Prof. Masayuki Sato (Shibaura Institute of Technology), Prof. Mitoshi Nishimura (Seitoku University), Mr. Shigeru Sugasawa (Shibaura Institute of Technology Senior High School). This research was approved on the ethics aspect under the Shibaura Institute of Technology Senior High School. This work was conducted in part at the Plant Transgenic Design Research Center within the Gene Research Center, with Graduate School of Life Environmental Sciences, University of Tsukuba, Japan.

Notes

[1), 2)] Knowledge has been considered to divide into two types: one is explicit knowledge, which is easily determined through texts, and the other is tacit knowledge, such as knack, which is defined as "knowledge that is hard to express and transfer to the other." Tacit knowledge is though to be acquired through experience, and can be classified into a wide variety of types (Polanyi 1958, 1966, Nonaka and Takeuchi 1995, Spear and Bowen 1999, Leonard and Swap 2005, Mori 2005).

REFERENCES

Chandler, P. and Sweller, J. (1991) Cognitive load theory and the format of instruction. *Cognition and Instruction* **8** (4): 293-332.

Hara, N., Alsarhan, H., Kilburn, J., Ynalvez, M., Ynalvez, R. and Chen, K.H. (2010) Learning tacit knowledge in life science graduate programs in Taiwan. *Proceedings of the American Society for Information Science and Technology* **47**(1): 1-5.

Hatogai, T. (2011) *Research Report on "A Research Project on the Development and Evaluation of the Systematic Learning Program in Biology Nurturing Students' Respect for Life."* (in Japanese)

Kawakami, S. and Kato, M. (2004) Improvement of the experiment on the somatic cell division using "Squash method with slide glass" and its practical study in the junior high school. *Bulletin of Center of Research, Training and Guidance in Educational Practice, Aichi University of Education* **7**: 175-180. (in Japanese)

Leonard, D. and Swap, W. (2005) *Deep Smarts: How to Cultivate and Transfer Enduring Business Wisdom,* Harvard Business School Press, Waltertown.

Meijer, P. C., Verloop, N. and Beijaard, D. (1999) Exploring language teachers' practical knowledge about teaching reading comprehension. *Teaching and Teacher Education* **15**(1): 59-84.

Majerich, D. M. and Schmuckler, J. S. (2008) *Compendium of Science Demonstration-Related Research from 1918 to 2008*, Xlibris Corporation, United States.

Merkt, M. and Schwan, S (2013) Training the use of interactive videos: effects on mastering defferent tasks. *Instructional Science*. in press.

Merkt, M. and Schwan, S (2014) How does interactivity in videos affect task performance? *Computers in Human Behavior* **31**: 172-181.

Ministry of Education, Culture, Sports, Science and Technology, Japan. (1999) *The Courses of Study for Middle Schools in Japan, December 1998, Explanation of Science*, Dainippon Tosho Publishing Co., Ltd., Tokyo. (in Japanese)

Mori, K. (2005) *Handbook of Instruction of Skill & Technology*, JIPM Solutions, Japan. (in Japanese)

Nakatake, T. and Nakayama, H. (2006) Problems in observation of somatic cell division in a junior high school: Theory-ladenness to be seen in an observation result of students. *Research Report of Japan Society for Science Education* **21**(2): 35-40. (in Japanese)

Nonaka, I. and Takeuchi H. (1995) *The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation*, Oxford University Press, Oxford.

Polanyi, M. (1958) *Personal Knowledge*, University of Chicago Press, Chicago.

Polanyi, M. (1966) *The Tacit Dimension*, Routledge & Kegan Paul, London.

Robertson, S. L. (2005) Re-imagining and rescripting the future of educational: global knowledge economy discourses and the challenge to education systems. *Comparative Education* **41**(2): 151-170 .

Smith, B. K and Reiser, B. J (2005) Explaining behavior through observational investigation and theory articulation. *The Journal of the Learning Sciences* **14**(3): 315-360.

Spear, S. and Bowen, H. K. (1999) Decoding the DNA of the Toyota Production System. *Harvard Business Review, September-October.*

Sweller, J. (1988) Cognitive loads during problem solving: Effects on learning. *Cognitive Science* **12**: 257-285.

Taylor, C. (1988) *The Art and Science of Lecture Demonstration*, Taylor & Francis, New York, London.

Tokyo Metropolitan School Personnel In-service Training Center, (2005) *Report of Research* *by Educational Researchers in FY 2004: Science*, (in Japanese)

Yonezawa, Y., Haruki, S., Shiraisi, N. and Kizito, M. E. (2006) An improved method for the observation of cell division using acetic dahlia solution in lower secondary school. *Japanese Journal of Biological Education* **46** (4): 199-205. (in Japanese)

Zanting, A., Verloop, N. and Vermunt, J. D. (2003) Using interviews and concept maps to access mentor teachers' practical knowledge. *Higher Education* **46**(2): 195-214.

Zhang, L. and Han, Z. (2008) Analysis on the management of college teachers' tacit knowledge. *International Education Studies* **1**(3): 21-24.

WEB RESOURCES

Central Council for Education (2004) The record of proceedings, (in Japanese), http://www.mext.go.jp/b_menu/shingi/chukyo/chukyo3/014/siryo/04071201.htm <accessed 21/02/2013>

Central Council for Education (2006) The report of Process of Discussion, (in Japanese) http://www.moj.go.jp/content/000004256.pdf <accessed 21/02/2013>

Central Council for Education (2008) The report of improvement on the Courses of Study of kindergartens, elementary, secondary and special schools, (in Japanese), http://www.mext.go.jp/b_menu/shingi/chukyo/chukyo0/toushin/__icsFiles/afieldfile/2009/05/12/1216828_1.pdf <accessed 21/02/2013>

Japan Science and Technology Agency, Center for Promotion of Science Education (2010) Investigation of actual conditions of high school science teachers in FY2008 (in Japanese) http://rikashien.jst.go.jp/highschool/cpse_report_009.pdf <accessed 15/08/2012>

Ministry of Education, Culture, Sports, Science and Technology, Japan. (2011a)The Course of Study; Elementary School Science, http://www.mext.go.jp/component/english/__icsFiles/afieldfile/2011/03/17/1303755_005.pdf <accessed 21/02/2013>

Ministry of Education, Culture, Sports, Science and Technology, Japan. (2011b)The Revisions of the Courses of Study for Elementary and Secondary Schools, http://www.mext.go.jp/english/elsec/__icsFiles/afieldfile/2011/03/28/1303755_001.pdf <accessed 21/02/2013>