Plant Biotechnology 23, 339–346 (2006)

Report

Gene literacy education in Japan—Fostering public understanding through practice of hands-on laboratory activities in high schools

Michiei Oto[1], Michiyuki Ono[2]*, Hiroshi Kamada[2]

[1] Department of Biotechnology, Tokyo Technical College, 1-15-5 Higashi, Kunitachi-shi, Tokyo 186-0002, Japan;
[2] Gene Research Center, University of Tsukuba, Tsukuba, Ibaraki 305-8572, Japan
* E-mail: miono@sakura.cc.tsukuba.ac.jp Tel: +81-29-853-7759 Fax: +81-29-853-7746

Received October 17, 2005; accepted February 1, 2006 (Edited by F. Sato)

Abstract Public understanding (PU) of biotechnology and life science is indispensable for developing bio-industry and life science itself. To promote PU, scientific literacy education, especially gene literacy education, should be introduced to the general public. An effective conduit for reaching a broad sector of society is high schools into which more than 95% of young people in Japan enter currently. Gene education involving laboratory activity is effective for obtaining literate students, because practical hands-on activities engage student's attention and deepen their understanding of biotechnology. The text "Recombinant DNA laboratory practice for secondary education" has enabled students to perform transformation experiments with safe host-vector systems in their classroom. Workshops for secondary school teachers have been held in a lot of universities since 2001, and currently gene literacy education involving laboratory activity is available in many high schools and public facilities including museums. To be most successful, we found that gene literacy education requires the collaborative efforts of teachers and scientists, and inter-school or intra-school cooperation status. In the present review, we summarize the current of gene literacy education in Japan.

Key words: Gene literacy, pGLO, public understanding, recombinant DNA laboratory practice for secondary education, scientific literacy education.

Biotechnology, including genetic engineering, cell culture, analytical technology with PCR and sequencing, has been promoting life science research since the 1970s. The development of life science and biotechnology has allowed scientists to start the modification of cells, and to accumulate genetic data for solving scientific problems and making new products. The recent innovations in life science have increased people's understanding of heredity, diseases, aging, evolution, and life itself. In medical science, genetic tests and gene therapy have already been put to clinical use, and in the food industry, products obtained through genetically modified organisms (GMOs) are available in many countries [The International Service for the Acquisition of Agri-biotech Applications (ISAAA): http://www.isaaa.org/].

As the pace of the progress is accelerating, the gap between scientists and the general public is becoming larger, and some people are apprehensive regarding genetic tests and GMOs. The improvement of new biotechnologies with unprecedented applications calls for a scientifically literate public and new methods for educating students.

The best way to overcome this apprehension regarding new technology is for the public to obtain basic knowledge of life science, understand biotechnology and discuss the matter with scientists. High schools are an effective conduit for gene literacy education, because more than 95% of young people enter high schools in Japan and they will become the general public in the future.

Hence, gene literacy education, which increases students' motivation and brings them up to be scientific literate public, is necessary to promote public understanding of life science and biotechnology.

Definition of gene literacy education

Gene literacy education is a kind of science literacy education involving laboratory activity related to life science, which allows the public to understand and

Abbreviations: ALDH2, aldehyde dehydrogenese type 2; ELSI, ethical, legal, and social issues; GFP, green fluorescent protein; GMO, genetically modified organism; MEXT, the Ministry of Education, Culture, Sports, Science, and Technology; PU, public understanding; RFLP, restriction fragment length polymorphism; SNP, single nucleotide polymorphism; SPP, science partnership program; SSH, super science high school.
This article can be found at http://www.jspcmb.jp/

discuss issues based on scientific knowledge and a scientific way of thinking. Such education includes practical hands-on laboratory activities, and the learning of basic knowledge through laboratory work and discussion. Hand-on activities stimulate students' imagination and will increase their understanding of science, which will motivate general students and make talented students accept greater challenges in life science.

Laboratory work makes invisible molecular events visible. For example, transformation is a technique commonly used in cloning and various biotechnology procedures. When students transform bacteria by themselves, they can learn basic concepts of life science involving the central framework of life (DNA to RNA, protein and traits), and gene expression and gene regulation. While comparing transformed bacteria with control bacteria, students will learn basic ways for studying scientifically through experiments. Moreover, students can have challenging discussions to understand ethical, legal, and social issues (ELSI) behind science and technology.

Hence, gene literacy education is to learn basic life science through laboratory activity.

Gene literacy education in schools

According to statistical data obtained by MEXT; http://www.mext.go.jp/english/statist/index.htm, more than 96% (2003) of students who graduate from junior high schools enter high schools, and 47.3% (2003) of them enroll in universities after graduation from high schools in Japan.

Therefore, a major conduit for gene literacy education is high schools. Moreover, junior high schools and non-biological departments of universities are also effective conduits for gene literacy education, because a lot of the prospective general public study in them. Museums, which unspecified public visit, are also effective conduits. Thus, gene literacy education could be available not only in secondary school, but also in other school systems.

Critical factors to promote gene literacy education

In the end of 20th century, adoption of the Cartagena Protocol on Biosafety and completion of working draft of the human genome heightened public awareness of biotechnology. Therefore, gene literacy education for public understanding became more needed than before. However, gene literacy education was far from the classroom because of some barriers due to the circumstances of schools and education before 2001. Major barriers were as below.

Recombinant DNA laboratory activity was restricted by the Guidelines for Recombinant DNA Experimentation

When DNA cloning and analysis involving recombinant technology were performed, inspection according to guidelines by the safety committee established in each facility was indispensable. However, it was difficult to establish safety committees in general secondary schools and museums.

Teacher's skills as to laboratory work on recombinant DNA were not satisfactory

Most teachers had no experience of recombinant DNA experiments, and no opportunity to learn the guidelines and rules for recombinant DNA laboratory work.

Molecular biology laboratory activity involving PCR and electrophoresis was restricted by the budget from the government

Laboratory activities involving DNA analysis could be conducted regardless of recombinant DNA guidelines. However, the budget for laboratory activities was not satisfactory, therefore it was difficult for teachers to purchase expensive equipment and reagents for laboratory work on DNA analysis and molecular biology.

Gene literacy education was restricted by Curriculum Standards

Until 2003, molecular biology and biotechnology were not emphasized in the Curriculum Standards, therefore they were less focused in the textbooks authorized by MEXT.

In primary and secondary schools in Japan, teachers must conduct all lessons on all subjects according to the Curriculum Standards, and only authorized textbooks can be used for school education.

Therefore, it is difficult to conduct gene literacy education in these schools.

Dramatic changes in secondary school education since 2001

Establishment of "Recombinant DNA laboratory practice for secondary education"

The necessity of gene education involving recombinant DNA laboratory activity has previously been discussed by scientists and teachers, and some tentative trials were conducted in the 1990s (Kainuma 1991; Kainuma 1993; Yoshioka 2001).

When the former Ministry of Education, Culture and Sports, and the former Science and Technology Agency were merged in 2001, each guideline for recombinant DNA experimentation was rearranged and revised. During this process, the text "Recombinant DNA laboratory practice for secondary education" was added to the revised guidelines. These new guidelines were enforced in 2002.

Biologically safe host-vector systems and donor genes, which are authorized and listed in the text of the guidelines, can be used in the laboratories of schools without a safety committee. An example of host-vector combinations is *E. coli* K12 as a host and a plasmid, which includes the green fluorescent protein (GFP) gene and the ampicillin resistant gene, as a vector.

Such host-vector systems are categorized as being exempt from NIH guidelines; http://www4.od.nih.gov/oba/rac/guidelines/guidelines.html, because they do not present a significant risk to health or the environment. According to the new guidelines, it is possible to conduct DNA education involving recombinant DNA laboratory work in the classroom regardless of other texts.

In November 2003, the Japanese government accepted the Cartagena Protocol on Biosafety, and the "Law Concerning the Conservation and Sustainable Use of Biological Diversity through Regulations on the Use of Living Modified Organisms"; http://www.biodic.go.jp/cbd/biosafety/pdf/LawVer.1.1.PDF came into force in February 2004. This law is a framework for protecting biological diversity from the potential risks arising from trans-boundary movements of genetically modified organisms (GMOs), and was based on the Cartagena Protocol on Biosafety.

After the guidelines became law in 2004, "Recombinant DNA laboratory practice for secondary education" was available in schools according to the law.

Launching workshops for school teachers in 2001

To prepare for laboratory activities based on "Recombinant DNA laboratory practice for secondary education", a workshop for science teachers was held at the University of Tsukuba Gene Research Center on August 2001, followed by in the Tokyo University of Agriculture and Technology Gene Research Center.

In the workshops, teachers had the chance to transform bacteria using plasmid DNA containing the GFP gene by their own hands. A snapshot of the workshop is presented in Figure 1. The transformation technique is basic recombinant experimentation and easy to introduce into the classroom, moreover, it is a good educational tool for introducing the framework of life and gene expression to students.

Figure 1. A snapshot of the workshop at Tsukuba University. High school teachers transformed bacteria using plasmid DNA containing the GFP gene by their own hands. Through hands-on activities, they learned the background of recombinant DNA and knacks of laboratory works to conduct laboratory activities in their classrooms.

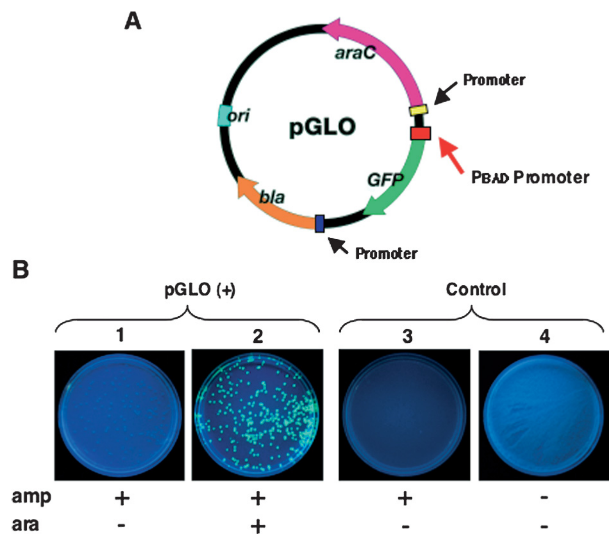

Figure 2. Structure of the pGLO plasmid and transformation of bacteria with the pGLO plasmid. (A) Plasmid "pGLO" is a 5371 base-pair-long circle, and carries three genes (*bla*, *araC* and *GFP*), the P_{BAD} promoter and the ori sequence. *bla* encodes beta-lactamase, and *araC* encodes the regulatory protein of the arabinose operon. *GFP* was derived from the intact GFP gene by means of DNA shuffling technique. The P_{BAD} promoter, which controls transcription of the GFP gene, is positively and negatively regulated by the araC protein. amp, ampicillin; ara, arabinose. (B) The strain of bacterium used in this experiment was *E. coli* K12 (HB101), and the medium was LB broth. Bacteria transformed with pGLO were resistant to ampicillin (plate 1) and emitted bright green fluorescence under long wave ultraviolet light in the presence of arabinose (plate 2), because of expression of the GFP gene. Control bacteria were not resistant to ampicillin (plates 3 and 4).

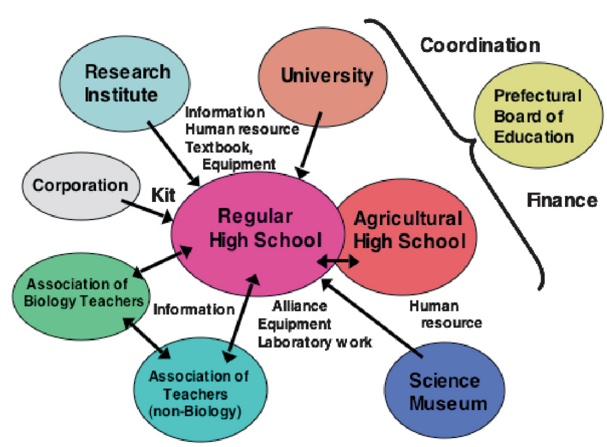

Figure 3. Relationship between alliances and collaborative partnerships among different organizations.

Table 1. Participants of workshops: the numbers of participants in workshops held at three universities are shown.

University	Year	JH	SH	J/SH	M	O	Total
University of Tsukuba, Gene Research Center	2001	1	13(3)	2	3	1	20
	2002	1	31(26)	1	1	2	36
	2003	4	31(3)	0	2	1	38
	2004	1	12(1)	1	6	2	22
	2005	0	21(2)	0	0	0	21
Tokyo University of Agriculture and Technology, Gene Research Center	2001	0	17(2)	3	0	0	20
	2002	5	13(1)	2	0	0	20
	2003	1	15(3)	2	2	0	20
	2004	0	18(2)	1	1	0	20
	2005	3	14(2)	2	1	0	20
Tokyo Gakugei University	2002	11	19(5)	1	1	0	32
	2003	17	14(2)	0	1	0	32
	2004	11	18(2)	0	0	0	29
	2005	22	10(3)	0	0	0	32

J. H., junior high school teachers; S. H, senior high school teachers; J/S. H, Junior-senior high school (Six years' private school) teachers; M, Museum scientists; O, others including scientists at universities. The numbers of vocational school teachers among high school ones is indicated in parenthesis of column H.

The purpose of the workshops was to introduce knowledge and skills regarding recombinant DNA for teachers to conduct laboratory activities in their classrooms. Therefore, the curriculum of the workshops included not only hands-on laboratory activities, but also lectures regarding to the role of gene literacy education in public understanding, the recombinant technology and its industrial application, and how to conduct laboratory activities in their classrooms according to the guidelines or the law relevant to "Recombinant DNA laboratory practice for secondary education".

Workshops have been held in many universities in Japan since 2002 (Kainuma et al. 2005). The numbers of participants in three universities are demonstrated in Table 1. Major participants were senior high school teachers including ones from vocational high schools, because gene literacy education is suitable for regular high school biology, and the excellent facilities in vocational high schools are effective for laboratory work. A follow-up survey of teachers who took part in the workshop at University of Tsukuba revealed that 42.9% of them conducted DNA education including hand-on laboratory activities in their classrooms within 1 year after the workshop.

In 2003, an advanced course was held in the University of Tsukuba Gene Research Center. Teachers, who had already had experience in conducting gene literacy education in their classrooms, took part in this workshop. They practiced higher level laboratory work including purification of recombinant proteins from bacteria and electrophoretic analysis of DNA. In the workshop, there was an opportunity for participants to discuss how to improve laboratory activities in their classrooms. In the discussion, major necessary factors for the progress of educational activity were budget and facilities.

In 2004, a workshop for home economy teachers was held in the University of Tsukuba Gene Research Center. The home economy courses in high schools are related to food science, and a section involving debate about GMOs is included in authorized textbooks. Therefore, the teachers had interest and apprehension regarding recombinant technology. The contents of this workshop included not only the transformation of bacteria, but also lecture and discussion on the safety of foods and GMOs.

New budgets for high school from MEXT

To support high school educational activities, MEXT has created new budgets described below since 2002. Super science high schools (SSH) are specialized high schools for science education, which are subsidized by MEXT to develop innovative curricula and laboratory activities. Frontier high schools are selected by the prefectural board of education designated by MEXT. In these high schools, teachers can develop new curricula and teaching methods to improve the knowledge of their students.

"Mezase"-specialist, which means "aspire to be" a specialist, is a program for excellent vocational high schools. In vocational high schools subsidized by MEXT, innovative curricula to make students more skillful and more creative regarding technologies should be developed and introduced for the students.

A science partnership program (SPP) is an alliance of schools with universities and research institutions. SPP is put into three categories, which are (1) Visiting-scientists; special classes by visiting scientists, (2) Cooperation; a learning program for students given at universities and research institutes, and (3) Workshops for teachers; Operation at a training program for teachers on cutting edge science. These new budgets were based on the "Science Literacy Enhancement Initiatives" (Kagakugijyutu, Rikadaisuki plan) and related policies, whose purpose is the fostering of scientific and technological human resources for the future handling of technology innovations and stronger industrial competitiveness (White paper on science and technology: http://www.mext.go.jp/english/news/2005/04/05051301/part1/01-03.pdf).

Revision of Curriculum Standards

Since 2003, high school biology courses have been conducted according to the Curriculum Standards, which were revised in 1999. In the revised Curriculum Standards, "the structure and function of the gene" contents were improved and "biotechnology" was introduced as an elective subject, "advanced biology" (Seibutsu II), into high school curricula, and authorized text books were published. Therefore, recombinant DNA laboratory activity became effective for the implementation of "advanced biology".

Kits are effective for hands-on laboratory activity

Generally, reagents and equipment for molecular biology experiments are too expensive and difficult to purchase by high schools. Kits for education have a lot of advantages for promoting hands-on laboratory activity in the classroom. The advantages of available kits are described below.

(1) Materials and workstations are included.
Materials and workstations for laboratory activities are provided, and micro-pipettes and special equipment are not necessary. Therefore, it is easy for school teachers to conduct such activities in their classrooms.

(2) Kits are not expensive.
The price of a kit is lower than the total price of all the materials if purchased separately.

(3) Kits are adaptable to various curricula.
According to a curriculum, laboratory activities make the contents understandable to students. Teachers can use the kits in lessons, depending on the depth of information they want to impart.

At the present time, there are few schools and museums with the facilities and equipment to conduct basic hand-on molecular biology experiments. For this reason, kits and equipment should be easy to obtain and simple to use. Kits which produce reliable results in the hands of students will be indispensable for the process of integrating biotechnology into education in Japan.

Therefore, in the workshops described above, a pGLO plasmid including the green fluorescent protein (GFP) gene (Prasher et al. 1992; Chalfie et al. 1994) was selected as an educational material (Figure 2) for transformation. In this system, the GFP gene is modified through improved cycles of DNA shuffling, followed by screening for the brightest *E. coli* colonies (Crameri et al. 1996). In *E. coli*, most of the wild-type GFP ends up in inclusion bodies and thus unable to activate the chromophore. On the other hand, a modified protein exhibits higher solubility and higher fluorescent intensity, therefore, it is easy to use and suitable for laboratory activities in education.

At the end of the experiment, bright colonies will impress students regarding gene expression. The GFP gene regulated by the araC protein derived from a vector containing the arabinose operon (Guzman et al. 1995) is effective for explaining the regulation of gene expression to students.

A transformation kit including the pGLO plasmid is commercially available (pGLO bacterial transformation kit: Bio-Rad Laboratories, Herculus, CA) and easy to introduce into a laboratory activity in the classroom. The pGLO bacterial transformation kit was tentatively used in a science workshop for high school teachers sponsored by the former Ministry of Education, Culture and Sports, at the Tokyo Technical College in 1998, and it was agreed that the kit enables efficient implementation and standardization of a laboratory activity in the high school classroom in Japan because of the reproducibility of experiments and easy-to-use tools.

Cases of gene literacy education in various facilities

Currently, there are many cases of gene literacy education in the classroom in Japan. Some typical cases are described below.

Super science high school (SSH)

Ritsumeikan High School was designated as a super science high school from 2002 by MEXT (http://www.ritsumei.ac.jp/fkc/topics/ssh/index-e.htm). In this high school, a new subject, "Life", was created as a compulsory subject for 2nd grade students (K-11, 16–17 year old students). For the new subject, the teachers developed a new text book, which contained chapters of basic cell biology, molecular-based human biology, basic presentation skills for reporting results and discussing of experiments.

The curriculum involves recombinant DNA laboratory activity, which include 10 hours lectures and 3 hours of laboratory work involving the transformation of *E. coli* with the pGLO plasmid and discussion. Through the lessons, some of the students have become interested in not only life science but also ELSI behind science.

Advanced biology (Seibutsu II)

At Tokyo Gakugei University Senior High School

Oizumi Campus, students have the opportunity perform recombinant DNA laboratory work in advanced biology. The curriculum involves a transformation experiment on *E. coli* with the pGLO plasmid. The course includes 2 hours of lessons about the biological background and rules of recombinant DNA laboratory work, followed by 3 hours of laboratory work and discussion.

Frontier high school

Fukushima Meisei High School was designated as a Frontier high-school by the board of education of Fukushima prefecture. From 2003 to 2005, this high school has been subsidized by MEXT. The curriculum that was created through collaboration between teachers and a scientist includes hands-on laboratory activity involving commercially available pGLO transformation kit and a hand-made SNP genotyping unit.

In addition to studying the central frame of life and gene regulation through transformation experiments, students are introduced to genome science through single nucleotide polymorphism (SNP) genotyping of the aldehyde dehydrogenese type 2 (ALDH2) gene, which has been reported to be related to alcohol-sensitivity and the alcohol-flush reaction (Crabb et al. 1989). In the genome science laboratory activity, students extract their own genomic DNA from cheek cells and detect SNP (G or A) at codon 487 of the ALDH2 gene by means of PCR-restriction fragment length polymorphism (RFLP) technique, which involves PCR amplification with modified primers (Ando et al. 1991) of extracted genomic DNA, followed by restriction endonuclease digestion and gel electrophoretic analysis. After staining the gel, students can see whether SNP of the ALDH2 gene on their own genomic DNA is heterozygous (G/A) or homozygous (G/G or A/A) by observing the stained bands on the gel. Finally, to protect the genome information, students destroy the genomic DNA specimens with 1 M HCl.

Through the laboratory activity, students learn not only the concept of genome information but also how to analyze genomic DNA, moreover, they have the opportunity to discuss ELSI concerning personal information located on genomic DNA.

Museum

In the "Science World—Gifu Research Information Center", which is a museum located in Gifu prefecture, recombinant DNA laboratory activities have been conducted several times for many people, including high school teachers, high school students and the general public. This workshop, subsidized by SPP of MEXT, involves the transformation of bacteria according to "Recombinant DNA laboratory practice for secondary education".

Prospective systems to improve gene literacy education

The primary phase of gene literacy education has been proceeding as "seeding in schools". In the secondary phase, alliance and collaborative partnerships are the keys to promote gene literacy education. Recently, financial support by the government has been initiated and has provided to several specified schools. In many other schools, unsatisfactory facilities, a tight financial situation and a lack of specialized teachers are critical factors hampering the implementation of gene literacy education. In these circumstances, know-how for laboratory activities should be shared with many teachers.

Collaborative partnership between high-school teachers and scientists

Scientists can give students lectures concerning the cutting-edge of science, which are not in the high school curriculum. Moreover, if students visit a university or research institute, they can perform laboratory activities at the bench, using equipment for real scientific investigation. Hence, collaboration between high school teachers and scientists will provide students with opportunities to have higher quality lessons involving laboratory work. Currently, such collaboration is being designated by SPP. Collaboration between teachers and scientists might build new networks, which can connect real science with education. To make such networks more effective, information related to cutting-edge scientific topics, teaching materials, know-how of laboratory work and workshops should be concentrated on a portal site, from which teachers can always select and download data. Based on the data, they can improve text books, and create educational materials for practical laboratory work.

Inter-school alliance (Alliance between high schools)

Generally, the facilities at regular high schools are unsatisfactory for laboratory work because of the emphasis on lessons in classrooms, however, vocational high schools, especially agricultural high schools, have authentic facilities and teachers who are competent in practical laboratory work involving recombinant DNA. An alliance between regular and vocational high schools will enhance laboratory activities in regular high school lessons, and activate academic activity in vocational high schools.

Intra-school collaborative partnership (collaboration among science, home economics and other teachers)

Home economics is a unique subject including food science, nutrition and cooking. Through collaboration between home economics teachers and biology teachers, students are able to learn about food and nutrition from different points of view, and then can discuss GMOs based on scientific knowledge. When science teachers want to introduce ELSI to students, they should collaborate with ethics teachers. Hence, collaboration might compensate for shortfalls in the contents of one subject, and make gene literacy education more sophisticated.

From network to consortium

Through such alliances and collaborative partnerships as those described above, various networks have already been formed independently. When the networks are systemized and become a consortium, it will bring about synergy effects and promote gene literacy education, because a consortium involves various human resources and academic systems.

Currently, many high school teachers have taken part in workshops, however, some hesitating in conducting laboratory activities remains, due to inadequate budgets, equipment, experience, know-how, etc. Some consortiums have already been launched.

In the Chugoku area of Japan, five universities, i.e., the Gene Research Centers of Hiroshima University, Tottori University, Shimane University, Okayama University and Hiroshima University, have constructed a consortium to support school teachers. Every summer, scientists in the consortium hold workshops for teachers and award them diplomas.

In Gifu prefecture, four institutes, i.e., Gifu University Life Science Research Institute, Gifu Prefectural Education Center, Science World–Gifu Research Information Center and Gifu International Institute of Biotechnology Foundation, become allied as a consortium to support classroom activities including laboratory work. In this consortium, the organizers are scientists at Gifu University.

The consortium: http://gumail.cc.gifu-u.ac.jp/~lsrc/conso/ has planned and conducted workshops for school teachers and released know-how of "Recombinant DNA laboratory practice for secondary education" on their website.

In the Tsukuba district of Ibaraki prefecture, a consortium comprising the prefectural board of education, universities, research institutes, science museums, the local association of biology teachers and companies has been planned and will soon be launched. In the consortium, the prefectural board of education plays the role of the organizer to support teachers who want to conduct "Recombinant DNA laboratory practice for secondary education" in their classrooms. Scientists at universities, research institutes and science museums supply textbooks and teaching materials, and officers of the prefectural board of education consult with teachers about budgets and facilities, and play roles as negotiators with the government.

The local association of biology teachers functions to promote the creation of new educational materials and methods of instruction. The relationship between an alliance of facilities and collaborative partnerships of teachers and scientists is described in Figure 3.

A consortium might be very more effective for supporting teachers and promoting gene literacy education, as described above. However, to complete a consortium, an organizer with leadership is necessary. Scientists and officers, who have talented as to scientific education and negotiation, should help to construct a consortium.

New kits should be developed

To compensate for the unsatisfactory facilities at schools, kits including reagents and equipment are very important for education. A kit for molecular based analyses of genes related to traits might be used to learn Mendelian law. A kit for extraction of genomic DNA from human cells, and analyses of SNP and repetitive sequences might be used to learn genetic information and to discuss ethical problems. Usually, kits have been supplied by commercial firms, but scientists in universities, research institutes and museums have the potential to develop kits and thus might supply teachers. It was tentatively reported that scientists in a museum have developed kits and supplied school teachers (Ushijima et al. 2003).

Conclusion

Students have a lot of potential to grow up into not only scientists but also other specialists, including journalists, public officers and so on. Promoting gene literacy education in high schools will enable students to discuss and debate real issues based on science, and finally will produce literate people who can accurately understand new concepts of life science and new biotechnology including GMOs and genetic medicine. In Japan, the establishment of "Recombinant DNA laboratory practice for secondary education" was a breakthrough that accelerated laboratory activity in the classroom and promoted gene literacy education. To be most successful, the collaborative efforts of teachers and scientists, and inter-school or intra-school cooperation have already been initiated. Hence, it is certain that the practice of hands-on laboratory activities in high schools will foster scientific literacy and public understanding of life science and new biotechnology.

Acknowledgements

The authors thank Dr. Junichi Saito for the critical comments and helpful discussions, and Dr. Tohru Suzuki, Dr. Nobukazu Tanaka, Mr. Naoaki Tamura, Mr. Kazuaki Kubota, Mr. Yasuhiro Shigihara and Mr. Jin Ito for the experienced information regarding gene literacy education. This work was supported in part by a Research Grant of Life Science Program, MEXT.

References

Ando M, Maruyama M, Oto M, Takemura K, Endo M, Yuasa Y (1991) Higher frequency of point mutations in the c-K-ras 2 gene in human colorectal adenomas with severe atypia than in carcinomas. *Jpn J Cancer Res* 82: 245–249

Chalfie M, Tu Y, Euskirchen G, Ward WW, Prasher DC (1994) Green fluorescent protein as a marker for gene expression. *Science* 263: 802–805

Crabb DW, Edenberg HJ, Bosron WF, Li TK (1989) Genotypes for aldehyde dehydrogenase deficiency and alcohol sensitivity. The inactive ALDH2(2) allele is dominant. *J Clin Invest* 83: 314–316

Crameri A, Whitehorn EA, Tate E, Stemmer WP (1996) Improved green fluorescent protein by molecular evolution using DNA shuffling. *Nature Biotechnol* 14: 315–319

Guzman LM, Belin D, Carson MJ, Beckwith J. (1995) Tight regulation, modulation, and high-level expression by vectors containing the arabinose pBAD promoter. *J Bacteriol* 177: 4121–4130

Kainuma K (1991) Laboratory experiments on genetic transformation.: Teaching method and evaluation. *Jpn. J. Biological Education* (*Seibutsu Kyouiku*) 31: 115–134 (in Japanese)

Kainuma K (1993) Practical research on teaching materials for bacterio phage. *Jpn. J. Biological Education* (*Seibutsu Kyouiku*) 33: 154–172 (in Japanese)

Kainuma K, Oto M, Nakajima H, Saito J, Iida H, Harada K, Kobayashi K (2005) The present realization and future prospective of DNA education for high school biology teachers analysis of questionnaires conducted during recombinant DNA courses. *Kagaku Kyouiku Kenkyu* 29: 248–264 (in Japanese)

Prasher DC, Eckenrode VK, Ward WW, Prendergast FG, Cormier MJ (1992) Primary structure of the *Aequorea victoria* fluorescent green protein. *Gene* 111: 229–233

Ushijima K, Komiya T, Takakuwa Y, Fujiwara M, Tashiro H (2003) A strategic plan of corporation in museum management. —Co-production and reciprocal use of delivery kits by museum and schools.— *Bulletin of Japan Museum Management Academy* 7: 17–24

Yoshioka N (2001) An extension lecture and experiment course of DNA genotyping for the high school students. *Jpn J Electroph* 45: 37–40