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Laboratory work as a teaching method: A historical case study of the institutionalization of laboratory science in Japan

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Abstract: Practical work, including laboratory work, has been part of science education for more than a century, and is considered an essential component of science teaching. This paper uses historical insights to demonstrate that there is a pressing need to critically examine the role of laboratory work in science teaching. The author performed a historical case study of laboratory work in Japan from the 1880s to the 1930s. Given that the West, particularly the United Kingdom and United States, has influenced Japanese education since Japan began to modernize in the late 19th century, this study refers to the history of those nations with respect to laboratory work, and compares their educational system to that of Japan. The author concludes that practical work (including laboratory work) should be considered a means to an end - not an end in itself - with teachers sufficiently educated/trained in both science and pedagogy, functioning as facilitators who provide students with learning support. Without enthusiastic and knowledgeable teachers, the benefits of quality facilities and an established system cannot be fully realized. Thus, in conducting practical work, emphasis ought to be placed on its purpose and what students can learn from the experience - not on merely the actions they perform in conducting such work.

Keywords: laboratory work; heuristic method; laboratory teaching method; Japan; the United Kingdom; the United States.

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1. Introduction

When compared to other school subjects, *rika* (Japanese science education) (Ogawa, 2015) involves a great deal more practical work and very few educators would deny the importance of practical work in science teaching. However, some science educators (e.g., Hofstein & Lunetta, 1982; Hodson, 1998; Osborne, 1998) have raised questions around practical work. Hodson (1991), for example, argued

that «despite its often massive share of curriculum time, laboratory work often provides little of real educational value. As practiced in many countries, it is ill-conceived, confused and unproductive» (p. 176).

Why is practical work an essential feature of science education? Further, when did it become essential, and how effective is it as a teaching and learning strategy? Throughout this paper, the author uses and focuses on the term «laboratory work», which refers to any activity related to the learning or teaching of science (whether carried out individually or in a small group) in a school laboratory and that primarily involves observation, experimentation, and investigative work. This contrasts with «practical work» which entails fieldwork, as well as observation, experimentation, and manipulation of the objects/materials being studied, and other scientific activities (e.g., investigations inside or outside of the laboratory for the purpose of teaching/learning science). Hence, laboratory work is an essential part of practical work. The author prefers the term «laboratory work» rather than «practical work» because this study primarily focuses on the heuristic method as practiced in school laboratories. This method was first proposed by Henry E. Armstrong (1848-1937), an academic chemist in the United Kingdom, who studied chemistry in Germany, worked at colleges as a teacher in England and devised the heuristic method in the 1880s. His research would subsequently influence the practice of science teaching in early 20th century Japan.

Since Japan began to modernize in the late 19th century, it has been influenced by the West - particularly the United Kingdom and United States - and science education is no exception. By comparing the history of laboratory work in Japan with that of the United Kingdom (primarily England) and the United States, this comparative study shows that there is a pressing need to rethink the role of laboratory work in science teaching. Thus, based on the case of Japan, the author considers laboratory work from a global perspective.

2. The Emergence of Experimentation in Japanese Schools

Following the Meiji Restoration in 1868, the new central Japanese government employed many *oyatoi gaikokujin* (foreign advisors) to hasten the modernization of society by establishing a nationwide school system, from elementary schools to university level. Likewise, some students were sent to study disciplines such as science and education (involving teacher education) in the West.

During that time, Japanese education was influenced to some extent by the United Kingdom and United States, as well as by other Western countries. For example, some books in the *Science Primers* series were imported and translated into Japanese, and subsequently used as elementary and secondary-level textbooks. According to the authors of *Science Primers*, this series aimed to expose students to scientific knowledge produced by professional scientists while also training them in scientific methods (e.g., Stewart, 1872; Roscoe, 1872). Most units in the textbooks included a simple experiment conducted by teachers that aimed to demonstrate a specific scientific principle.

According to an annual report released in 1876 by the Department of Education (later renamed the Ministry of Education or *Monbusho*, in Japanese), the Japanese

translations of *Science Primers: Chemistry and Physics* (and other textbooks) were often used in reading courses (*The Monthly Journal of Monbusho*, 1876). This was not only attributable to an absence of suitably-trained science teachers and a lack of convenient apparatuses for experiments, but also to traditional teaching methods, whereby it was common to read translated books from China or the West (with accompanying lectures in Japanese) concerning the interpretation of words and terms.

The aforementioned approach to learning from other cultures was practiced for a significant period of time. Knowledge from foreign cultures was expressed in Japanese and interpreted according to the Japanese context. However, when the culture of origin was not fully understood, the knowledge extracted from it was often misconstrued (Isozaki, 2014). Except for a few traditional sciences such as *wasan* (Japanese arithmetic), the modern form of science in Japan was largely imported from the West. Laboratories or adequate apparatuses for science teaching did not exist; accordingly, the government established the Education Museum (now called the National Museum of Nature and Science) in 1877 to supply and display educational tools, including apparatuses and specimens.

Despite an absence of conditions conducive to effective experimentation, two prominent professors named Makita Goto (1853-1930) and Kenjiro Nakagawa (1850-1928) managed to produce some simple physics and chemistry apparatuses, as well as edit books for conducting experiments (e.g., Goto, Shinoda, Takizawa & Yagyu, 1885; Goto & Miyake, 1885; Nakagawa, 1891). According to Goto *et al.* (1885), the purpose of their books was to illustrate how to conduct experiments, use and make simple apparatuses, and devise questions for students. In the preface to Nakagawa's (1891) book entitled *Kan'i kagaku kikai* (Simple Apparatuses for Chemistry), he asserted that teachers should construct simple apparatuses for science teaching. The simple apparatuses created by Goto and Nakagawa were subsequently awarded gold and silver medals at the international exhibitions in the United States and United Kingdom.

In 1895, Yoshioka translated Frederic Guthrie's (1877) book of physics experiments into Japanese and included his own original illustrations, since the original version contained no figures (Yoshioka, 1895). Guthrie (1833-1886) was employed as a physics professor at the Royal School of Mines, where he gave lectures on practical physics at a summer school for science teachers (Turner, 1927) using simple self-constructed apparatuses (*Nature*, 1875). *Nature* (1879) praised Guthrie as having simultaneously «invented several experimental methods at once interesting, ingenious, and simple» (p. 311). Guthrie gave his simple physics apparatuses and the related materials to the Education Museum, which led to the beginning of experimentation in Japan using simple apparatuses (Tanahashi, 1941). Brock (1998) asserted that Guthrie «played a significant posthumous role in rendering Japanese science teaching less didactic and more practical» (p. 8).

Consequently, many physics and chemistry textbooks containing simple experiments were published in Japan during the 1880s and 1890s. Whereas some were translations of Western texts, others were original works by Japanese authors. At the time, simple experiments involved teachers purchasing or creating

simple apparatuses intended to demonstrate and help students understand specific scientific concepts in a classroom - not to have students conduct experiments in a laboratory.

3. The Institutionalization of Laboratory Science in Japan

3.1. *How the Heuristic Method was Taught in Japanese Schools*

In the early 20th century, the typical environment for teaching physics and chemistry at boys' secondary schools consisted of a single classroom dedicated to both subjects, or occasionally separate classrooms for each (Kikuchi, 1909). No provisions were made for students to carry out practical work except in one or two schools. It was not until at least 1911 that a revised regulation advised science teachers to provide students with opportunities to conduct simple experiments as much as possible (Monbusho, 1940). Tokuhei Kametaka (1872-1935), a professor at the Tokyo Higher Normal School, first introduced a syllabus created by the Incorporated Association of Headmasters, which was based on Armstrong's heuristic method. Some boys' secondary schools in Tokyo and other areas (such as the cities of Nagano and Wakayama prefectures) established laboratories wherein students engaged in laboratory work; prior to 1911, science teachers also held several meetings on laboratory work by students (e.g., Kametaka, 1904; Nakagawa, 1979).

A new generation of leaders - including Gentaro Tanahashi (1869-1961) and Chinji Oshima (1874-1960), who graduated from the Tokyo Higher Normal School where Goto was a professor - had the opportunity to study abroad, especially in England. They began to play an active role in promoting the practice of science teaching in Japan. After they returned, they enthusiastically integrated Armstrong's heuristic method into Japanese science education by publishing articles and books; in addition, they gave lectures in Tokyo, Hiroshima, and other locations. As an inspector at the Ministry of Education, Professor Tanahashi played a key role in promoting laboratory work based on Armstrong's heuristic method.

3.2. *The Promotion of Laboratory Work by the Central Government*

During the early 20th century, both external and internal factors played a role in terms of improving physics and chemistry laboratory work at boys' secondary and normal schools. The external factors related to the beginning of World War I, which effectively halted trade between Japan and other countries (namely Germany), especially with respect to importing medical supplies, industrial raw materials, and machinery. Consequently, at the domestic level, some policymakers and members of the National Diet (Japan's bicameral legislature) recognized the importance of promptly educating many scientists and engineers, and the promotion of research and development in science and technology. *Riken*, for example, was founded in 1917. The enhancement of science education, specifically in physics and chemistry, was hence prioritized as an effective means to strengthen the nation (Tanahashi,

1918, 1941; Itakura & Yagi, 1974). This policy strongly reflected the aims of the syllabi for physics and chemistry, which the Ministry of Education published in 1918 (Monbusho, 1940). As mentioned above, World War I brought about significant changes in thinking about science; for example, the human development of scientific careers, and science curricula or courses in pre-professional education in Japan.

Regarding domestic factors, there was growing enthusiasm among science educators toward conducting physics and chemistry laboratory work due to Goto and Nakagawa's efforts, as well as the introduction of Armstrong's heuristic method.

The Ministry of Education implemented three strategies at boys' secondary and normal schools that were intended to improve physics and chemistry teaching by integrating student-conducted laboratory work into lessons, as well as the institutionalization of laboratory science:

1. *Innovation in teacher education.* To hold a nationwide conference for physics and chemistry teachers comprising of workshops and seminars, and to revise science curricula at the Tokyo and Hiroshima Higher Normal Schools.
2. *Improving science-teaching facilities.* To create a special budget for building laboratories and purchasing laboratory apparatuses.
3. *Developing/reorganizing the educational system.* To create physics and chemistry syllabi that focused on *seito jikken* (student-conducted experiments), and to revise physics and chemistry regulations in boys' secondary and normal schools.

The nationwide conference that aimed to explain the new policy, managed by the Ministry of Education, spanned four days in September 1917; it was also considered a form of in-service teacher training and included participants from each of Japan's 47 prefectures. Schools and local boards of education held meetings about the conference after participants returned to their respective prefectures in order to develop ideas for laboratory work (Kataoka & Isozaki, 2003). Thus, the Ministry of Education's policies were disseminated through regulations and syllabi, as well as the conference's participants.

The first two days of the conference were held at Tokyo Higher Normal School and the attached boys' secondary school, whereas the remaining two days were held at the Ministry of Education. Tanahashi, who was a member of the committee responsible for creating syllabi for physics and chemistry experiments, gave lectures on the heuristic method, and reinforced the importance of laboratory work conducted by students. He described the heuristic method as follows:

The laboratory teaching method...entails reaching conclusions based on data from student-conducted experiments, while also promoting creativity and a sense of inquiry, as well as teaching students not to blindly accept certain theories.

Someone mentioned that it is unnecessary for an instructor to teach anything in the classroom when students are engaged in laboratory work under the heuristic method. Even though the laboratory work should be considered fundamental to teaching science, it alone does not provide adequate scientific knowledge. Therefore, using an appropriate textbook is necessary to supplement an idea that may not be wholly clear from an experiment.

Experiments should be based on the heuristic research method, and teachers ought to avoid adopting old-fashioned approaches (*The Bulletin of the Tokyo Academy of Physics*, 1918, pp. 422-423: reported by Matsushita).

Tanahashi introduced the heuristic method as a «laboratory teaching method» at the conference, and did not discuss in detail Armstrong's six steps, which emphasize observation, hypothesis-based reasoning, and enabling students to be discoverers (Armstrong, 1903).

Oshima (1920) argued that the heuristic method not only entails performing laboratory work, but also providing training that will enable one to acquire knowledge both broadly and scientifically. Tanahashi and Oshima strongly believed in Armstrong's heuristic method, especially with respect to the notion that student-conducted laboratory work could improve the teaching and learning of science in Japan. Nevertheless, they recognized other valid approaches to the teaching and learning of science, and stressed the importance of demonstration, fieldwork, and other practical work. They introduced the heuristic method as just one of the science-teaching methods discussed in their books (Tanahashi, 1913, 1918, 1941; Oshima, 1917, 1920, 1935).

The Ministry of Education allotted approximately 200,000 Japanese yen for the purchase of apparatuses and building of laboratories. Despite legislation that required laboratory work to be conducted, the Ministry's budget was insufficient to ensure that this occurred at all boys' secondary and normal schools; ultimately, the remaining costs became the responsibility of local governments and taxpayers, or benefactors' contributions. Budgeting issues, in addition to varying degrees of enthusiasm among teachers and principals, caused efforts toward improving physics and chemistry teaching (including laboratory work) to differ between prefectures and schools (Kataoka & Isozaki, 2003; Sakai & Isozaki, 2005). In introducing the American, British, and German laboratory environments to Japan, Oshima (1918) offered a detailed proposal to establish and design laboratories and apparatuses, respectively, and argued for the importance of creating laboratories in girls' secondary schools as well.

The syllabi edited by the Ministry of Education were published in 1918. A year later, the Ministry extended the time allotted to physics and chemistry lectures in order to ensure opportunities for laboratory work. The syllabi were similar to those adopted for elementary science by the Incorporated Association of Headmasters in the United Kingdom, which Kametaka, Tanahashi, and Oshima had introduced to Japan. However, the Ministry's syllabi merely included lists of experiments, and lacked guides for instruction. This is noteworthy since prior to 1918, for teachers and students, Tanahashi and Mori had edited laboratory notebooks of physics (1914) and

chemistry (1916); these included a title, apparatuses, procedures, and conclusion. Tanahashi and Mori asserted the following:

The laboratory teaching method is considered a practical heuristic method since it causes students to become discoverers who engage in observation and experimentation independently. In science teaching today, students are given problems to solve and conduct observations and experiments individually in order to solve such problems in a laboratory. Following this, in the classroom, the instructor must comment on the work that students complete (Tanahashi & Mori, 1914, 1916, p. 2).

They strongly argued that a laboratory notebook was necessary to guide laboratory work. As a result, laboratory notebooks were often published alongside authorized textbooks in the years after 1918.

As a traditional element of Japanese teaching culture, the concept of «lesson study» (Isozaki & Isozaki, 2011; Isozaki, 2015; Isozaki, 2016) provided teachers with opportunities to improve their teaching skills, including the management of laboratory work. For example, the boys' secondary schools attached to the Tokyo and Hiroshima Higher Normal Schools provided «open-house lesson study» for teachers. In addition, some associations for physics and chemistry teachers held conferences on laboratory work. Likewise, scientific and educational magazines, as well as the bulletins of various organizations, published issues of laboratory work after 1918.

3.3. *The Impact of the Heuristic Method in Japan*

Tables 1 and 2 show the status of physics and chemistry facilities in 1921 and 1928, respectively.

Table 1 The Conditions of Physics and Chemistry Facilities in 1921

Types of lecture room and laboratory				No. of Schools	Ratio(%)
Physics lecture room	Physics laboratory	Chemistry lecture room	Chemistry laboratory		
○	○	○	○	1	0.8
Shared with Chemistry room	○	Shared with Physics room	○	14	8.7
○	○	A common room for lecture and laboratory		5	3.11
A common room for lecture and laboratory		A common room for lecture and laboratory		9	5.59
Shared with Chemistry room	Shared with Chemistry lab	Shared with Physics room	Shared with Physics lab	105	65.22
One room for teaching Physics and Chemistry both for lectures and laboratories				7	4.35
No lecture room and no laboratory for teaching Physics and Chemistry				20	12.42

Note: There were 385 boys' secondary schools in 1921, and responses were received from 161 schools. This survey was conducted by the boys' secondary school attached to the Hiroshima Higher Normal School. (Source: Kataoka & Isozaki, 2003)

Table 2 The Conditions of Physics and Chemistry Facilities in 1928

Types of lecture room and laboratory				No. of Schools	Ratio(%)
Physics lecture room	Physics laboratory	Chemistry lecture room	Chemistry laboratory		
○	○	○	○	14	4.46
Shared with Chemistry room	○	Shared with Physics room	○	44	14.57
○	Shared with Chemistry lab	○	Shared with Physics lab	4	1.32
○	○	A common room for lecture and laboratory		22	7.28
A common room for lecture and laboratory		○	○	7	2.32
Shared with Chemistry room	Shared with Chemistry lab	Shared with Physics room	Shared with Physics lab	107	35.43
A common room for lecture and laboratory		A common room for lecture and laboratory		58	19.21
One room for teaching Physics and Chemistry both for lectures and laboratories				30	9.93
No lecture room and no laboratory for teaching Physics and Chemistry				16	5.3

Note: There were 544 boys' secondary schools in 1928, and responses were received from 302 schools. This survey was conducted by the boys' secondary school attached to the Hiroshima Higher Normal School. (Source: Kataoka & Isozaki, 2003)

Regulations and syllabi provided by the Ministry of Education allowed facilities for laboratory work to develop rapidly. Ten years after regulations were enforced, most schools had opened laboratories, despite difficulties with respect to budgeting or hesitation on the part of teachers.

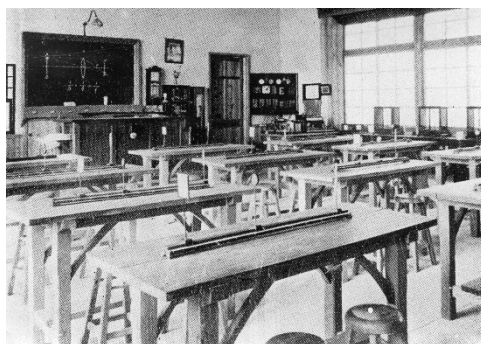


Plate 1: Physics laboratory at the boys' secondary school attached to the Hiroshima Higher Normal School (Source: This picture has been owned by the department of science education, Hiroshima University).



Plate 2: Class in a chemistry laboratory, Hiroshima school (Source: Science Study Group of the Hiroshima Higher Normal School (1932)).

Plates 1 and 2 illustrate the kind of laboratories in which physics and chemistry were taught at the time. The physics laboratory (Plate 1) at the boy's secondary school attached to the Hiroshima Higher Normal School was established in 1918, where Oshima was a professor. Using these newly established physics and

chemistry laboratories, the first open-house lesson study on teaching physics and chemistry including, laboratory teaching methods, was held by the boys' secondary school attached to the Hiroshima Higher Normal School in 1920. Compared with laboratories in the United Kingdom at that time (Jenkins, 1979), these laboratories seem to have been built with reference to the British model.

Unlike in the United Kingdom, criticism of the heuristic teaching method in Japan was limited, probably because the Ministry of Education used national policy to directly promote physics and chemistry laboratory work conducted by students. Moreover, influential leaders such as Kametaka, Tanahashi, and Oshima were professors at the Tokyo and Hiroshima Higher Normal Schools, which were hubs for educational research and teacher training. In the United Kingdom, many actors such as the government committee (Thomson Committee, 1918), the scientific community (the British Association for the Advancement of Science [BAAS], 1918), and the community of science teachers (*School Science Review*, 1929) ended up criticizing Armstrong's heuristic method. When compared to cases in the United Kingdom, in Japan, there were fewer educators (and scientists) to offer criticism. Laboratories for natural history (in subjects such botany, zoology, and geology) were also built during this time, and teachers of natural history could produce instructional apparatuses through financial support from local governments, schools, and other sources (such as parents and benefactors). As mentioned previously, many laboratory notebooks were published by science educators (such as Tanahashi and Kametaka) without the Ministry's approval. The experiments in such notebooks adhered to a similar structure; they included a title and description of the experiment's aims, procedures/methods, and results, followed by a conclusion. Students were expected to develop inductive reasoning by conforming to prescribed procedures. However, this «recipe» or «cookbook» approach whereby students carried out procedures mechanically, without deep reflection or engagement, may have caused them to lose sight of the intended purpose of laboratory work, especially since such approaches were often designed to lead students directly to the correct results. Likewise, in the United Kingdom, many teachers developed a worksheet called the card system (Woolnough & Allsop, 1985). Hodson (1993) argued that Armstrong's approach emphasized doing science in order to understand it; consequently, standardized experiments in laboratory notebooks led students to follow recipes in order to verify theories, the goal being to illustrate scientific concepts under teachers' instruction. Terakawa and Brock (1978) characterized the application of the heuristic method in Japan as slavish and as making learners susceptible to becoming blind followers.

Notwithstanding some negative aspects of the implementation of the heuristic method, its adaptation was subsequently expanded to include natural history subjects at boys' secondary schools and the integrated subject «science» at girls' secondary schools, rather than being based on the Ministry's regulations and syllabi (Kataoka & Isozaki, 2003). Unlike in the United Kingdom, laboratory work in Japan filtered down to elementary schools (Kanbe, 1922, 1938; Oshima, 1920). In England, institutions with historical ties to universities, such as grammar and independent schools, were the primary centers that adopted practical science teaching based on Armstrong's heuristic method. It was not until the second half of the 20th century that schools targeting most of the country's population began to teach practical science on a

significant scale (Jenkins, 1998). The Education Reform Act, which required science to be adopted as a core subject in primary schools, was not passed until 1988.

As some researchers asserted (e.g., Oshima, 1920; Terakawa & Brock, 1978), the institutionalization of laboratory science in schools after World War I was the first case of the Japanese government providing comprehensive efforts and encouraging one specific school subject.

4. Discussion

4.1. *Why Was the Heuristic Method Criticized, and Who Were its Critics?*

Armstrong (1903) described the aims of science teaching as being to «cultivate the intelligence and develop the faculties of observing, comparing, and reasoning from observation» (p. 222). He argued that «heuristic methods of teaching are methods which involve our placing students as far as possible in the attitude of the discoverer - methods which involve their *finding out* instead of being merely told about things» (p. 236, *italics* in original). He added that one goal of practical heuristic studies is to develop faculties by providing mental training in the scientific method. At the annual BAAS conference in 1899, he (1903) described his idea of physical science lessons based on the heuristic method. There were six stages, as follows: Stage 1 - Lessons on common familiar objects, which involve description from observation, as well as classification; Stage 2 - Lessons in measurement; Stage 3 - Studies of the effect of heat on things in general, and of their behavior when burnt; Stage 4 - The problem stage, which describes thirteen problems such as determining the nature of changes and how they affect burning substances in air, separating the active from the inactive constituent of air; Stage 5 - The quantitative phase, which provides quantitative determination of the composition of a compound; and Stage 6 - Studies of the physical properties of gasses in comparison with those of liquids and solids, which introduce the molecular and atomic theories. Woolnough and Allsop (1985) argued that only the fourth stage fully exemplified the heuristic approach.

Jenkins (1989) asserted the role of the laboratory in developing a habit of thinking scientifically, which involved the mental training and intellectual characteristics of practical scientists. This is because practical training was an integrated part of both pre-professional secondary school science curricula and university courses for scientific careers. Therefore, science, along with other academic subjects such as literature and mathematics, could be firmly situated within the secondary school curriculum.

However, in the early 20th century, there were many criticisms of the heuristic method. The following statement from the Thomson Committee (1918) strongly criticized Armstrong's approach:

...many teachers have become so dominated by the idea of the supreme value of experimental work that they have left on one side and neglected those sciences which do not lend themselves to experimental treatment in school ... But sometimes the performance of laboratory exercises has been considered

too much an end in itself - such an exercise loses the educational value of a real experiment when it becomes a piece of drill;

Much of this waste of time is due to a conscientious desire of the teachers to encourage the spirit of inquiry by following the so-called heuristic method... but it seems clear that the heuristic method can never be the main method by which the pupil acquires scientific training and knowledge (Thomson Committee, 1918, pp. 55-56).

The Board of Education (1911) also reported that the method of learning by doing «is not the only method» (p. 79). Furthermore, critics of the heuristic method argued that it promoted a narrow-minded approach to science teaching, wherein practical work in the laboratory was considered an end in itself, and other methods were consequently overlooked. The Consultative Committee on Secondary Education (Board of Education, 1938) argued that the doctrine of formal discipline or the transfer of training that underpinned heurism would collapse in the early years of the 20th century.

Although advances with respect to understanding the psychology of learning (Brock, 1973; Jenkins, 1989) and shifts in science education's aims (Uzzell, 1978; Layton, 1973) also underline criticism of Armstrong's heuristic method, perhaps the most valid criticism centers on variations in teacher competency. Jenkins (1979) noted that the heuristic method was misapplied by inexperienced or inadequate teachers in the early 1900s. Westaway (1929) was critical of the term «heuristic» and maintained that the method «presupposes a very small class [size] and a gifted teacher» (p. 25). Moreover, Westaway (1929) asserted that Armstrong never revealed the secret of his method, and suspected that he «was unaware of its true nature himself» (as cited in Brock, 1973, p. 49). Richmond and Quraishi (1964) argued that the misunderstanding of Armstrong's heuristic method was because Armstrong never published a book on his method, while Jenkins (1979, 1989) claimed that Armstrong's heurism contained an inherent educational paradox. The BAAS committee (1918) discussed this paradox in 1917, and maintained that it had arisen from the false assumption that «the scientific method is an abstraction which does not exist apart from its concrete embodiments» (p. 134). Indeed, the heuristic method was too novel and challenging for many teachers to adopt effectively (Uzzell, 1978).

Despite efforts by the Ministry of Education and professors of science education (not academic scientists) in Japan, the overall outcome of implementing the heuristic method was disappointing. Tanahashi (1941), Oshima (1935), Kanbe (1922, 1938), and Kōno (1953) identified four problems: (1) The inability of teachers to fully grasp the heuristic philosophy; (2) A lack of enthusiasm and competency among instructors with respect to managing laboratory work, which was time-consuming; (3) Inadequate laboratory facilities at some schools owing to insufficient funding, as highlighted in Tables 1 and 2; and (4) A tendency for laboratory work to be removed from or unrelated to students' interests. Furthermore, since the practical skills acquired through laboratory work were not needed to pass entrance exams, the heuristic method and its associated time-consuming laboratory work alienated both teachers and students, who could not see its immediate benefits for students (Tanahashi,

1941). Considering the context of the United Kingdom, it might be doubtful how far Japanese leaders really understood Armstrong's heurism.

According to Rosen (1954), in the United States a major impetus for the shift toward laboratory teaching between 1887 and 1900 was the publication of the *Harvard Lists* in 1886, which included 40 detailed laboratory exercises for high school students (Rudolph, 2005). In its *Report of the Committee of Ten on Secondary School Studies* (National Education Association, 1894), the National Education Association asserted the importance of discipline-based education and noted the «absolute necessity of laboratory work by the pupils» (p. 27) in learning science. The publication of Cooke's *Laboratory Practice* (1891) marked the first attempt at creating a chemistry course composed of laboratory work in the United States (Smith & Hall, 1910).

Overall, the influence of Armstrong's heuristic method was less pronounced in the United States compared to Japan. Mann (1910) asserted that in the United States, «the most powerful influence in shaping the course of study, including laboratory work, in secondary schools has been that of colleges and universities» (p. 229). This was also the case in the United Kingdom, and can explain why Armstrong's methods were less influential there. Mann attributed the failure of the heuristic method in the United States to: (1) An inability to use laboratories effectively; (2) Neglecting to teach concepts pertinent to students' daily lives or that provided solutions to immediate problems; (3) An overemphasis on passing examinations; (4) Teachers' limited understanding of concepts; and (5) Concepts not being presented clearly in textbooks.

Smith and Hall (1910), who advocated for laboratory-based learning, recognized both the merits and shortcomings of the heuristic method. In doing so, they favored an inquiry-based approach to laboratory work that aimed at a meaningful understanding of concepts. DeBoer (1991) noted that between 1900 and 1920, efforts were made to make science education more practical, real, and relevant to students' lives; one of these attempts involved adopting William Heard Kilpatrick's (1871-1965) project-based approach to laboratory work.

By the time science education scholars introduced the heuristic method to Japan, the general science movement was already under way in the United States and United Kingdom. The general science movement was influenced by reflecting on and criticizing the heuristic method and laboratory work, which was time-consuming. In contrast, when general science arrived in Japan in 1931 by means of government regulations, similar reflection and/or criticism regarding laboratory teaching did not arise (Isozaki, 2016).

4.2. *Scientific Knowledge versus Scientific Training*

The historical perceptions of science education's aims underpin arguments in science teaching regarding the relative importance of content/knowledge or method/process.

In the United Kingdom, practical science - which refers to science teaching that includes lectures and teacher demonstrations, coupled with student engagement in practical work - was considered a vehicle for mental training and developing practical skills (e.g., observing, reasoning) from the 1860s until the early 20th

century, specifically in the fields of physics and chemistry. An 1867 BAAS report (1868) asserted that the goal of science teaching was to disseminate scientific information and provide scientific training; whereas the former refers to scientific content/knowledge, the latter embodies a method/process to some extent.

According to Thomas H. Huxley (1825-1895), science entails «nothing but *trained and organized common sense*» (1895, p. 45, *italics* in original), and that «the great peculiarity of scientific training...is this bringing of the mind directly into contact with fact, and practicing the intellect in the completest form of induction...in drawing conclusions from particular facts made known by immediate observation of Nature» (p. 126). Huxley championed the scientific method's merits, which included mental training; nevertheless, it failed to advance beyond demonstrations and object lessons. As noted by Curtis (1965), «the Heuristic method sounded the death-knell of the old object lesson» (p. 296). Armstrong's heuristic method garnered strong support for scientific training; however, the introduction of general science in the 1910s caused emphasis to be placed on scientific knowledge/content as opposed to method/process.

As for the Japanese context, Oshima (1937) maintained that «the realization or acquirement of scientific training involves not only acquiring knowledge of the material world, but obtaining valuable culture and discipline as well» (p. 8); thus, from Oshima's perspective, scientific training surpassed scientific knowledge in importance. Nonetheless, he warned against old-fashioned learning based primarily on acquiring knowledge from textbooks. Traditionally, elementary and secondary science education in Japan has focused on three components: (1) Knowledge/understanding; (2) Skills; and (3) The affective domain (Isozaki, 2014). The 1918 syllabi reflected this latter notion. For example, the syllabi asserted that teaching methods should be improved (especially with regards to focusing on experiments), and that learners should acquire knowledge and skills that would benefit the country, while fostering creativity and a spirit of voluntarism (Monbusho, 1940).

In the United States, Smith and Hall (1910) referred to the ideas of H. Spencer, J.G. Macgregor, and Huxley to identify five objectives of science education: (1) To learn by observing the natural world; (2) To learn through comparison and induction; (3) To use one's imagination and stimulate creativity; (4) To learn through self-elimination; and (5) To implement useful information. Moreover, like Huxley and BAAS, Smith and Hall agreed that scientific training and knowledge comprised the study of science. Their conceptualization of scientific training was not based on object lessons and demonstrations; however, they did not overemphasize the role of sophisticated laboratory work. Smith and Hall tried to overcome the heuristic method's weakness via an «inquiry» based approach.

As noted by Kerr (1963), the heuristic laboratory teaching method fortified the notion that science teaching was a laboratory - rather than a classroom - affair. Likewise, an examination of its implementation in Japan, the United Kingdom, and the United States provides an overview of what factors were deemed crucial for effective laboratory work in each respective nation. It is essential to note that Armstrong's approach prompted arguments concerning teaching to shift from questions such as «Why teach science?» to «How should science be taught?» (Uzzell, 1978),

especially in the United Kingdom and Japan. However, as observed by Gott and Duggan (1995), radical changes in the aims of science teaching should be avoided. Hence, this historical case of the heuristic method of laboratory teaching exemplifies the importance of achieving a balance between the aims of science teaching.

Between the 1960s and 1980s in the United States, we can observe the development of science curricula that focused *both* on the logical structure of the disciplines of human investigation, as well as on the processes or skills of science supported by new psychologists and scientists such as Jerome Bruner (1960) and Joseph Schwab (1962). At the same time, in the United Kingdom, science curricula were developed by the financial support and initiatives of the Nuffield Foundation. Richmond and Quraishi (1964) concluded that Armstrong's heurism was returning once more in the 1960s. Jenkins (1989) called this trend «neo-heurism» (p. 39), and pointed out that the «Tyler-Bloom» (p. 39) model of curriculum design quickly became the accepted way to plan a curriculum. These science curricula were introduced into Japan and translated into Japanese, and the result, that scientists as well as science teachers enthusiastically studied not only curriculum materials produced by both countries but also their background philosophy, led to the revision of the course of study for secondary science.

4.3. *Laboratories as Reflections of Culture*

A given nation's culture has often affected the introduction of laboratory teaching therein. By exploring cultural differences, it is possible to identify and learn from them, as well as reflect on aspects of one's own traditions that might otherwise be taken for granted.

For example, Rosen (1954) examined the rise of physics teaching in laboratories in American secondary schools between 1821 and 1910. Amongst the four factors he identified that had led to its adoption was the «peculiar optimistic American habit of popularizing to emotional extremes certain 'progressive' ideas» (p. 204).

Oshima (1937) maintained that for Japanese students, the benefit of scientific training was greater in practical instruction due to a sense of weakness in the national characters of the Japanese people. In comparing facilities for laboratory teaching and how they were organized between the United States, the United Kingdom, Germany, and France, Oshima (1935) noted that traces of each country's respective national character were evident. For instance, whereas British laboratories were robust, practical, and led by instructors who implemented the heuristic method, American laboratories were large in scale and led by instructors who used them to help students understand scientific concepts. Oshima's assessment of American laboratories is corroborated by Mann (1910), who asserted that educators in the United States were attempting to make the best possible use of their laboratories to determine whether the results justified the time and money invested in laboratory work. In comparing the status of laboratory work between England, Germany, and France, Smith and Hall (1910) maintained that despite advances in European nations, it remained primarily an American phenomenon. They further asserted that «the best secondary schools in America...have little or nothing to learn from [their counterparts] in France, Germany, [and] England» (Smith & Hall, 1910, p. 370).

5. Conclusion

Oshima (1920) and Kanbe (1922, 1938) identified three prerequisites for successfully science teaching that have been proven historically to be true: (1) Adequate facilities; (2) A thorough system comprised of regulations and orders; and (3) Well-educated teachers. This last item is especially important since without enthusiastic and knowledgeable teachers, the benefits of quality facilities and an established system cannot be realized.

This historical examination of the implementation of laboratory work in Japan, the United Kingdom, and United States clearly demonstrates that practical work, including laboratory work, is a means to an end - not an end in itself - with teachers sufficiently educated in science as well as professional education, providing students with learning support. Thus, in conducting practical work, emphasis should be placed on its purpose: why students conduct practical work and what they can gain from the experience of learning science - not merely the actions performed while carrying it out.

6. References

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