Innovations and Technology Education

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1. Introduction

It is important for technology educators to teach technology in such a way that it reflects the 'real world' technology (De Vries and Tamir 1997). Technology education therefore needs to be kept up-to-date and to be innovated constantly. Also it should present a proper image of how innovations take place in the 'real world' technology. Thus there are good reasons to have innovation as a key issue for the 10th international PATT conference. In this introductory paper the concept of 'real world' innovations will be illustrated. This will be done by investigating the different ways innovation took place in industries. In particular the role of the industrial research laboratories as a source of and support for technological innovations will be described. The history of such laboratories shows different innovation patterns. Apparently there is not a single route for innovations, as sometimes is suggested by the flow charts that are used in technology education programmes. In that sense this paper can help us prevent naive ideas about innovations in technology education.

The history of a number of major industrial research laboratories has been written. Most early industrial research laboratories (founded in the late Nineteenth century) were chemical labs. Particularly in Germany we find examples of that. In the USA famous chemical industrial research laboratory are the Du Pont Labs. The history of these labs has been published (Hounshell and Smith, 1988). The chemical laboratories were followed by the electrotechnical labs. In the USA there were General Electric Labs and Bell Labs, the history of both of which has been published (Reich, 1977 and Wise, 1985). In Germany the Siemens company had research laboratories that have become quite famous. Apart from some short descriptions (Pfisterer, 1987 and Trendelenburg, 1975) there is not yet a written history of those labs. In the Netherlands it was the Philips company that started a research laboratory in the early Twentieth century: the Philips Natuurkundig Laboratorium (abbr. Nat.Lab., English: Philips Physics Laboratory). The author of this article has just finished a historical study into the history of this laboratory. This small survey shows that there is historical material available to study the innovations as they happened in a number of industrial research laboratories.

In this introduction to the PATT-10 conference a number of innovation patterns will be described. They have been derived from the written history of industrial research laboratories. Comparison of those written histories suggests similarities between several laboratories with respect to these innovation patterns. As a consequence it is not necessary to describe the history of each of these laboratories separately. Rather the focus will be on the different innovation patterns, and for illustrations the history of the various labs will be used as resources. The following three innovation patterns will be dealt with: (1) science serving as an enabler the realisation of technological innovations, (2) science serving an exploratory function for technological developments, and (3) science serving as a knowledge resource for technological developments. In the description of the labs there following features will be used: (1) the goals of the lab as the lab management perceived them, (2) the allocation and use of means, (3) the culture of the lab, (3) the structure of the lab, and (4) the way the lab tried to exert an influence through external contacts. Together these characteristics for each of the innovation patterns that we will meet, give an impression of how it functioned in practice.

2. Science as an enabler for technology (1900-1940)

As was mentioned in the previous section the industrial research laboratories were founded in a period of extension and diversification of their companies. There is some ambiguity of the exact role of the laboratories in this process. From our modern perspective we would, perhaps, expect the laboratories to play an explorative role in the diversification of the product portfolio of the company. The study of the history of the Philips Nat.Lab. (De Vries, yet to be published) in the period between WWI and WWII has shown that the laboratory did not play that role. It was primarily the directorate of the company - in this case in particular Anton Philips - that decided about the uptake of new products as an extension of the product portfolio. Philips started with one single product, the light bulb. In it's early years the Philips Nat.Lab. did measurement to test the quality of these bulbs, and also studied the natural phenomena of the bulbs in order to improve them. Also some research was done on tubes, as from a physics point of view these are closely related to light bulbs (there is glass and vacuum, and gas discharges). At a certain moment Anton Philips decided that Philips would move into the business of producing radio receiver bulbs, and later also radio receiver bulbs. Later he decided that Philips would produce complete radio sets, including loudspeakers (with electromagnets) and electric circuits. In the end the Philips company covered the whole system of radio, including broadcasting and transmission (Blanken, 1992). When these decisions had been taken, Holst received means to extend the Nat.Lab. in order to move into new research fields that were related to the new products. Later again, the company directors decided for further extension of the product range. Radio waves were also used for carrying telephone signals. The decision to move into the whole system of telephony (analogue to the decision to move into the whole system of radio), including telephone cables (with Pupin coils) and switching equipment. Via radio the company moved into the areas of sound equipment for auditoriums and other large rooms, microphones, and recording of sound. And each time the company decided for a new product the Nat.Lab. started to do research into that field. As all scientific know-how was concentrated in the Nat.Lab. and the factories had no research facilities, the Nat.Lab. also developed the new products and had pilot manufacturing under its roof. Later on the factories started their own laboratories that took over part of the development work. Then the development process was a back-and-forth movement between the Nat.Lab. and a factory (development) laboratory.

In the General Electric company in the USA the GE Labs also grew up together with the company as a whole. Although the existing historiographies do not accurately describe the interaction between product diversification of the company and research diversification in the lab, it is very well possible the same pattern as in Philips occurred there.

In this period science and technology are interwoven narrowly. The lab develops new knowledge that plays a vital role in the company's product diversification. It is the company's directorate that decides on product diversification and it is the lab that enables the company to realise the desire for diversification. There are short and often informal communication lines between the lab and the company's directorate. In the case of Philips, Anton Philips himself often visited the Nat.Lab. and discussed the product portfolio with Gilles Holst. In some cases the contact even went without Holst's intervention (Anton e.g. had direct contacts with Bouwers about X-ray equipment). Also the communication between the Nat.Lab. and the factories was direct and strait forward. There are no clear examples of the Nat.Lab. itself taking initiatives for suggesting possibilities for product diversification to the company's directorate. To the contrary, Holst in his meetings with the directorate often expressed his doubts about the commercial feasibility of a proposed product diversification (the strongest example of that is his resistance against the company's involvement in television before WWII).

To make the Nat.Lab. fulfil the role of enabler for product diversification, Holst stimulated academic excellence by inviting famous physicists to present at the lab's colloquium series, as was mentioned before, and at the same time kept emphasising the need for submitting patent proposals. Patents were very important in this phase of diversification because they protected the company's freedom of acting and if necessary preventing undesired actions by others. Several historians even mentioned production of patents as the primary motive for industrial companies to start industrial laboratories in the early Twentieth century (indeed in several cases the lab was initiated when patent legislation was established or renewed).

In terms of the features of the lab as a professional organisation, the characteristics for this period and the innovation pattern are:
- the primary goal of the lab as perceived by the management was to enable to company to reach its ambitions for product diversification;
- the means that were allocated to the laboratory increased in accordance with the growth of the company as a whole;
- a lab culture was created in which both academic and industrial excellence was stimulated;
- the organisational structure was still informal and strong individuals had ample chances for profiling themselves;
- the lab exerted an influence on the company by direct and informal contacts with the company's directorate and the factories.

The result was that the industrial labs served as an indispensable factor in the product diversification of their companies. They were really the driving forces behind the new business activities, although in many cases they may not have been the initiators of it.

3. Science as a forerunner of technology (1945-1970)

After WWII a strong belief in the role of science for technological developments emerged. The war had shown that the application of rather 'fundamental' research (nuclear physics) had unbounded enormous amount of energy. In the USA the president's scientific advisor, Vannevar Bush, produced a report entitled 'Science: The Endless Frontier'. The message of this report was that 'basic' research (research into the 'basics' of matter and energy, without a perspective on any concrete product) would always in the end resulted in technological (industrial) progression. Although almost none of the practical recommendations of the report were realised, it certainly played a role in the general attitude towards 'basic' or 'fundamental' science. In the Bell Labs, for example, several groups started to study quantum mechanics and solid-state physics. One of these groups invented the transistor, that from then on would serve as a 'proof' that already now some fruits from the new physics could be harvested. The maser, followed by the laser, was next examples of that. Not only in the Bell Labs, but also in many other industrial research labs, the interest in 'fundamental' research, in which the new physics played an important role, increased. The long-term product policy of the company in this perception would be primarily a matter for the industrial research labs. These labs would then serve as the forerunners for technological developments. In this period the 'technology as applied science' paradigm was very popular, although there were still other industrial fields in which the new physics did not play such an important role (e.g. in Philips the development of household appliances can be mentioned as an example of that).

In the Philips Nat.Lab. too the attention for 'fundamental' research grew. Here the motive was not only the fact that other labs followed that strategy, but also the new structure of the company as it had been defined shortly after the war (Blanken, 1997). New Product Divisions (PDs) had been defined, each with their own development labs. A Board of Management was created to manage the company as a whole, but the PDs had a certain level of autonomy to decide about their own product portfolio. The PD development labs more and more did their work independently of the Nat.Lab. The compact cassette for example was a Philips invention in which the Nat.Lab. was not involved at all. This brought the necessity for the Nat.Lab. to define its own profile and defend the necessity of their existence in the company. The general belief in 'fundamental' science of that time yielded a good opportunity for that and in the 1950s and 1960s the Nat.Lab. perceived that type of research as typical for itself, compared to the PD development labs. In the management meetings there was a continuous scanning of new scientific developments to see if a new field could be interesting to take up. This fitted quite well with the person who was in charge of the lab in this period, namely the well-known physicist Hendrik Casimir, who himself was well respected by such famous physics colleagues as Bohr and Pauli (Casimir, 1983). Thus the lab became involved e.g. in laser research and research into such phenomena as superconductivity and superfluidity. Evidently the company's Board of Management did not object to this as they gave the Nat.Lab. a fair share of the wealth of the company that was created by the favourable economic circumstances of the 1950s and 1960s. In that time there were ample opportunities for bringing new products to the market, and the Nat.Lab. strategy could possibly bring forward totally new options for that. The Nat.Lab.'s idea was that they would use their 'fundamental' research to come up with totally new technologies and products and transfer prototypes to the PDs for further development and production. At the same time they continued to do research that was related to existing or planned concrete products, and as in the previous period, the Nat.Lab. wanted to do that by investigating the underlying phenomena. But as they saw the PD development labs as of a lesser scientific quality, more and more they decided to extend their development work so that the research output would be 'spoilt' by the PD lab because of their lack of expertise. A very difficult relationship between the Nat.Lab. and the PDs existed for many years (De Vries, 1999). On the one hand the PDs felt that they had no say in the Nat.Lab.'s research programme and that most research output had to commercial relevance, and on the other hand the Nat.Lab. was frustrated by much research output left unused by PDs. There was a mutual lack of commitment that greatly frustrated the contacts between the Nat.Lab. and the PDs at management level (at workfloor level often the personal contacts were not so bad, and individual Nat.Lab. employees often were prepared to help the PD factory in case of practical problems).

In terms of the features of a professional organisation, the Nat.Lab. in the 1950s and 1960s can be characterised as follows:
- the goals of the industrial research lab now became more focused on 'fundamental' (i.e. not yet oriented on a concrete product) research as a unique contribution to the company; the lab's role in supporting the development by gaining understanding of the underlying phenomena remained;
- the lab had the opportunity to do 'fundamental' research (with great uncertainty of the usability of the outcome) because there were ample means available;
- the academic side of the lab culture was enhanced and there was a continuous interest for new scientific developments;
- the structure of the lab became more hierarchical and formalised (as in the rest of the company);
- it was difficult to exert an influence on the rest of the company and 'ivory tower' and 'island' probably are the best metaphors to describe its relationship with the PDs.

Similar characteristics can be found for other industrial research labs in this period.

As the transistor in the Bell Labs could be used to justify this innovation pattern as appropriate for that time, the Nat.Lab. could show two big successes: the Plumbicon television pickup tube and the LOCOS process for making Integrated Circuits (ICs). Both were the result of the Nat.Lab. strategy to do 'fundamental' research and later derive new products and technologies from that (Sarlemijn and De Vries, 1992). The initial failure of the PD lab to prepare the Plumbicon for mass production strengthened the belief in the PDs' lack of scientific capabilities. The Nat.Lab. had to take back the design and later transferred it for a second time, after which successful production was possible. Both the Plumbicon and the LOCOS patents for a long time were the 'crown' patents of the company. On the other hand a lot of money was spent on research that never resulted in successful commercial activities. The Stirling hot gas engine research is a striking example of that (De Vries, 1993). Here we see how individual researchers had opportunities for continuing 'hobby horses' without any hard evidence for a future commercial success. Also the Video Long Play (VLP) is an example of a Nat.Lab.-driven product diversification that never became a commercial success. For a matter of fact a similar failure happened in the RCA Labs (Graham, 1986). Here too we find an industrial research laboratory with the ambition to serve as a forerunner for technological developments.

4. Science as a knowledge resource for technological developments (1970-now)

In the late 1960s and early 1970s a number of economical and social changes caused changes in the strategies of the industrial research labs, and a new innovation pattern pattern emerged.

In the first place the period of strong economic growth had come to an end. No longer companies could afford to bring out any new product to the market. In the second place an awareness of the negative effects of technological developments grew. Environmental problems, caused by the boundless use of technology, became evident. Also the belief in the stimulating role of 'fundamental' science had waned. All together this created new circumstances for industrial companies. Increased efficiency became a necessity. The money spent on all activities, including research, should have a high probability of yielding useful output.

As a consequence the industrial research laboratories had to reconsider their role in their companies. The effort into research with uncertain outcome had to be limited. More and more the PDs interests had to be taken into account for determining research priorities. Hard decision had to be taken to stop research lines (which in the past seldom or never had been necessary). No longer (almost) complete freedom for researchers could be allowed. Communication with PDs had to be improved to get a better understanding their needs. The industrial component of the lab culture had to be enhanced. The history of the Philips Nat.Lab. shows how difficult these changes were and how deeply rooted the old academically oriented strategy had become. Even though several new communication opportunities were initiated, both at the level of management and at workfloor level, the lack of mutual commitment was a serious barrier for a better co-operation between the Nat.Lab. and the PDs. It was not until 1989, when the company's Board of Management decided for a new way of allocating means for the Nat.Lab. that this commitment was forced upon the Nat.Lab. From then on the Nat.Lab. had to acquire two thirds of its budget from the PDs by offering research contracts to them. Thus the PDs got their say in the research programme and the Nat.Lab. got a guarantee that the PD used their output.

The changes did not mean a return to the first period of the Nat.Lab. and to the 'science as an enabler' innovation pattern. The PDs themselves had sufficient knowledge to be able to realise the product that they saw as possible future market successes. The Nat.Lab.'s role was more modest now: it served as a resource of knowledge. The fact that so many different disciplines were under one roof in the Nat.Lab. made this an interesting resource of PDs that usually had expertise in a limited range of disciplines. The development of the Compact Disc (CD) is a good example of this new innovation pattern. The CD was a PD (and not a Nat.Lab., as probably had been the case before 1970) initiative. But the realisation of this concept required such a wide variety of know-how (optical recording techniques, sophisticated signal processing, laser technology, highly precise mechanics) that the PD had to use the Nat.Lab. as a knowledge centre, where all these fields of know-how were present (partly because of the earlier VLP activities). But the requirements and conditions for the CD (e.g. disc size, recorded time) were defined by the PD and the development process as a whole was led by the PD (Lang, 1996).

In order to maintain the broad spectrum of know-how and at the same time to be able to acquire contract income from the PDs, the management of the Nat.Lab. developed a strategy in which capability portfolio maintenance and project activities were combined. In some cases Self Financing Activities (SFAs) were set up when no PD was found to be interested in a research topics that nevertheless by the Nat.Lab. itself was seen as important for the future. A company-wide rationalisation (Gruijthijsen and Van Junge, 1992) process (under the name of Centurion) enhanced the necessity to work client-oriented and to be focused on short-term PD interests. Already now some people in the PDs express their concern for the Nat.Lab.'s role in the long-term company policy.

When we consider the main features of the Nat.Lab. as a professional organisation in the period 1970-now we see the following:
- the goals of the lab became more and more PD-oriented and the research programme was adapted to the needs of the PDs;
- means were more limited now and the growth of the lab came to en end (new personnel could be attracted only by releasing scientists to PDs, which in the past had also happened, but then primarily with the motive of transferring expertise);
- the industrial component in the lab culture was enhanced (scientific interest was kept, but the was a stricter selection of taking up new research topics);
- the lab's organisational structure was extended with functions that were specifically related to the communication with the PDs (e.g. the so-called Research-PD co-ordinators);
- the lab now influenced the company by offering its knowledge to serve a role in the PDs product development processes.

Again, similar changes can be observed in other companies. The result seems to be that real breakthroughs are no longer the exclusive result of the effort of the industrial labs. The labs now have a subtler, but by no means less important, contribution to the technological developments within their companies.

5. Consequences for science and technology education

As we have seen there were different innovation patterns in different phases in the history of industrial research laboratories. This should make technology educators aware of the need to avoid the impression with pupils that innovations always take place the same way. Historical examples in technology can show them the richness of the 'real world' innovations. Innovating technology education by enhancing this element in the creation of a balanced concept of technology as a discipline and as a cultural phenomenon is quite important.

Thus this article has shown how historical research can serve as an information source for gaining an insight into 'real world' innovations. In particular for technology education this information is important, where there is no equivalent academic discipline to be used as a resource for curriculum development, the use of such studies is important. The same holds for the use of philosophical studies on technology, and for the discipline of design methodology as the systematic study of design processes. The exploitation of the outcomes of such disciplines for science education and technology education certainly has not been completed yet. For the future the interest in such disciplines among science educators and technology educators certainly deserves to be stimulated.

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