

Analysing Cases in Technology and Design Education: How could designing and making technological products be a vehicle for enhancing understanding of natural science principles?

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Abstract

Knowledge Promotion is the recent curriculum for the Norwegian 10-year compulsory school. Technology and Design (ToD) is a new main subject area in Natural Science. ToD should be taught across the curriculum between Natural Science, Art and Crafts, and Mathematics. The main goal is that pupils should be able to plan, develop and make useful products. The interaction between natural science and technology is a key part of this main subject area. Natural science principles constitute the basis for understanding technological activities. The present analyses of ToD education is based on case studies in three schools. The main outcome is that the actual ToD-project seems successful in developing pupils' skills in designing and making products, and has great potential to be a vehicle for enhancing understanding of adequate natural science principles. If carefully planned, this conclusion might be generalized to other ToD-projects.

Key words

Technology, design, natural science principles, project work, learning

Background, Aims and Frameworks

Before the *Knowledge Promotion* (KPO6, Utdanningsdirektoratet [Norwegian Directorate for Education and Training], 2006a) was implemented in 2006, Norway used less time for science and technology in compulsory education than all other countries in the OECD (Organisation for Economic Co-operation and Development, St.meld. nr. 30 (2003-2004), 2004:45). The situation is almost the same now. Natural Science is still a minor subject in compulsory education (7.8% of total time). ToD is one of six main subject areas in Natural Science because "natural science principles constitute the basis for understanding technological activities" (Utdanningsdirektoratet, 2006b:3). All main subject areas have competence aims to be reached after years 2, 4, 7 and 10. The number of competence aims in ToD, altogether 11 of a total of 105 in Natural Science in years 1-10, indicates that science-time used for ToD is limited. However, ToD "covers several subjects, including natural science, mathematics and art and crafts" (ibid.:3). Cross-curricular ToD-projects may allocate more than the limited science-time. Art and Crafts (Utdanningsdirektoratet, 2006c:2) have two main subject areas, Design and Architecture, which have many competence aims relevant

for ToD-projects. "Mathematics shows its usefulness as a tool when we work with technology and design" (Utdanningsdirektoratet, 2006d:1), but have no specific competence aims for ToD.

The present analysis consider only one, but a quite typical, ToD-project, designed to meet two competence aims in Natural Science after year 10 (end of compulsory education):

The pupil shall be able to

- develop products based on specifications that use electronics, evaluate the design process and assess product functionality and user friendliness
 - test and describe characteristics of materials used in a production process
- (Utdanningsdirektoratet, 2006b:9)

The relevant aims in Art and Crafts are:

The pupil shall be able to

- design products based on a technical specification of form and function
 - describe different solution for the design of a product using sketches and digital software
- (Utdanningsdirektoratet, 2006c:5)

Mathematics could easily be a relevant 'tool' in the project by using elements from aims in the main subject areas Numbers and Algebra, Geometry, Measuring (Utdanningsdirektoratet, 2006d:6).

The Natural Science Subject Curriculum claims that "the interaction between natural science and technology is a key part of this [ToD] main subject area" (Utdanningsdirektoratet, 2006b:3), and defines *natural science*:

Natural science is the result of human curiosity and our need to find answers to questions about our existence, life and life forms, and our place in nature and the universe, and in this way it becomes part of our culture. (ibid.:1)

The subject curriculum has no definition of *technology*, but the Core Curriculum for the whole KPO6 has a chapter named Technology and Culture (sic.), defining *technology*:

Technology is nothing more than the means humans have devised for achieving their goals, easing their work and cooperating better. (Utdanningsdirektoratet, 2006e)

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In KPO6 science and technology are defined and further described as very different human activities which have great influence on each other in our modern society. KPO6 addresses the interrelationship between science and technology by including ToD as a main subject area in Natural Science.

ToD could be included in the curriculum for different reasons. From the discussions in the late 1980s, Banks (1996) found four categories of arguments for introducing Design & Technology (D&T) in English compulsory education. For:

1. its intrinsic value: solving real problems, reflective thinking;
2. education for citizenship: important part of our culture, general technological understanding, citizen should be an informed opinion;
3. education for capability: can 'do' as well as 'know', practical curriculum for all to balance the academic;
4. economic importance: school technology linked to the country's economic performance.

The same arguments were sounded in the Norwegian debate around development of ToD from 1996 to 2006 (as can be seen in Hansen, 2007:45-50). Arguments 3 and 4 are instrumental (ibid.:47). The ministry had also another instrumental intention with ToD:

Integration of technology and design in curriculum for science and mathematics is a substantial contribution to strengthen the subjects' practical focus and status. (St.meld. nr. 30 (2003-2004), 2004:46, my translation)

As a main principle, KPO6 prescribes no pedagogical methods. The interpretation and implementation of the formal curriculum KPO6 is largely left to each school or teacher. They choose their teaching methods from total assessment of the actual competence aims, their pupils' abilities, the time allocated, physical framework, ... (as can be seen in Hansen, 2007:52-66). Bungum (2006) describes four ways to teach science and technology:

1. The relevant natural science principles are taught before the related technology.
2. The technology is taught before the relevant natural science principles.
3. Technology and science are taught separately.
4. Technology and science are taught as a 'seamless weave' – as a partnership.

The coupling of technology with design in KPO6 is a result of a long period of educational experiment and development starting in 1996, partly influenced by D&T in England (Hansen, 2007:24, 41). D&T is of Bungum's category 3. If taught using a cross-curricular approach, Norwegian ToD could be very different from English D&T.

However, we have adopted from England the intention of teaching the whole process from idea to finished product. This process is 'designing and making'. That's why Art and Crafts is the third partner subject should ToD be taught across the curriculum. Doing the whole process from idea to finished product is a light imitation of how professional designers, architects, engineers and entrepreneurs work on their projects. That's why the so called project-method (described as "project work" in the former national curriculum (Utdanningsdirektoratet, 1996)) often is favourable in cross-curricular ToD-teaching, as in the project being reported here. This imitation might give the pupils an insight into how our 'man-made-world' has developed from the first man to present. This world is the antagonist to the 'natural-world' which is the main focus in the subject Natural Science.

In Norway the publication of PISA (*Programme for International Student Assessment*, OECD, 2004) and TIMSS (*Trends in International Mathematics and Science Study*, IAE IEA, 2004) results from 2003 had some influence on both the political process leading to KPO6 and more strategic moves taken by the ministry. PISA looks at students' abilities to apply knowledge and skills in mathematics, science, reading and problem solving, and to analyse, reason and communicate effectively as they examine, interpret and solve problems rather than examine mastery of specific school curricula. That is the purpose of TIMSS. It collects educational achievement data to provide information about trends in performance over time together with extensive background information to address concerns about the quantity, quality, and content of instruction. In 2005 the education minister Clemet wrote:

The results from the international studies PISA and TIMSS make a discouraging picture of Norwegian pupils' knowledge and attitudes to science and mathematics. Particularly alarming is the decline from former studies. (Utdanningsdirektoratet, 2005:3, my translation)

Among different initiatives she took, was to "develop technology and design in relevant subjects in compulsory education" (ibid.:12, 31, my translation). The result was ToD in KPO6.

One strategic move taken is the co-national/Oslo project *Lead, Prioritize and Organise*. School development through a focus on results and teaching practice in Natural Science and Mathematics (LPO, my translation) (Utdanningsetaten [Department of Education Oslo], 2006) supporting the implementation of KPO6. Four of Oslo's 17 participating schools focus on ToD as a vehicle for enhancing understanding and knowledge of science and

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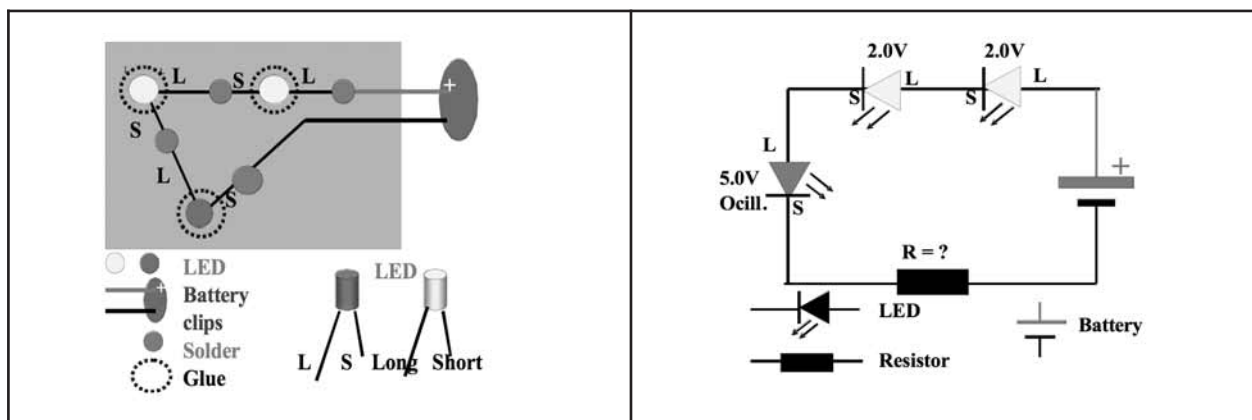


Figure 1. Cardboard with components (left). Coupling scheme (right). What resistor R must be placed in the circuit to prevent the LEDs from burning out and ensuring that all LEDs give light?

mathematics. I am the teachers' and school project groups' advisor in science and technology, working together with advisors in design. Three of the ToD-schools are objects for the present analysis. The specification for the project was the same at all schools:

You shall design and make an electronic badge with three diodes (LED), one oscillating. The badge should be made in plastazote from a template made of cardboard and paper. Maximum size is 12cmx12cm.

This project has been used in many schools in many different forms (for two descriptions see Paulsen, 2006 and EVINA, 2007) during the experimental period leading up to ToD in KP06, and is now part of the ToD 'canon'. The diodes are standard LEDs with a 2.0V characteristic, and 5.0V for the oscillating one. The diodes are soldered in series with a clip-in 9V battery, all glued onto a cardboard (Figure 1). Plastazote is cross-linked closed cell polyethylene (PE) nitrogen expanded thermoplastic foam. We use 6.0mm thick black or white as a relative stiff

background for the badge, and thinner 2.0mm sheet in different colours to make the details. The plastazote parts are 'baked' at 200°C in 2 minutes and then pressed together for 20 seconds. The diodes appear in three holes in the plastazote badge.

KP06 states that "natural science principles constitute the basis for understanding technological activities" (Utdanningsdirektoratet, 2006b:3), but does not discuss what is meant by 'natural science principles'. Given that the curriculum also states "the interaction between natural science and technology is a key part of ToD" (ibid.:3), 'natural science principles' is interpreted as understanding the science principles in the given context of a ToD-project, here the electronic badge project (Table 1).

In spite of LPO's general focus on science and mathematics, two schools (A, B) focused mostly on designing and making in the badge project. Their project lasted 7-8 hours, half and half on designing and making.

1	Electricity, electronics	Series and parallel circuits, components (resistors, conductors, semiconductors, isolators, batteries, diodes, LED), current [A], voltage[V], resistance [Ω], power [W] Less obvious: Generating and storing electrical energy, society's use of electrical energy, environmental aspects of electrical energy use.
2	Basic chemistry	The periodic system, in particular explanation of conductors, semiconductors and isolators, and metals' melting points (soldering).
3	Plastic chemistry	Thermoplastics and thermosetting plastics, types of plastics (PE, PP, PS, PVC, PET) Less obvious: Formation of fossil oil and gas, process from oil to plastics, environmental aspects of use of plastics.
4	Energy, heat, warm	Energy sources, types Less obvious: Energy laws, chains, quality.

Table 1. Natural science principles and concepts which could be taught during the electronic badge project

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The third school (C) followed my advice to put the project in what I call a *learning chain* with science and mathematics (Hansen, 2007:61) (Figure 2) *without* diminishing design and making aspects. The learning chain is a combination of Bungum's categories 1 and 4 (above). All C-classes started with 10-12 hours traditional hands on teaching to meet parts of one competence aim in KP06:

The pupil shall be able to explain results from experiments with electrical circuits using terms such as current, voltage, resistance.

(Utdanningsdirektoratet, 2006b:9)

The point is to establish the basic ideas and concepts about electrical circuits and components. This 'theoretical' start might have positive influence on designing and making (6 hours) and visa versa. During this process the pupils must use their acquired basic science principles, and they could further develop their knowledge in dialogue with fellow pupils and their teacher in a real context in order to solve practical problems. The result might be a stronger science 'knowledge-web' for electricity and electronics.

The learning chain was completed with 1-2 hours solving mathematical problems in the electronic badge context. This is good practice, but perhaps not the full intention in the curriculum: "Mathematics shows its usefulness as a tool" (Utdanningsdirektoratet, 2007d:1). To be a real 'tool', the pupils must use mathematics to solve the task in the specification. For instance to calculate the required values of resistors to put in the circuit to prevent the LEDs from burning out and ensuring that all LEDs give light (Figure 1). Since the actual LEDs had the given characteristics, this calculation was too easy. But if all three diodes were normal LEDs (2.0V), or the pupils wanted to use only one or two LEDs, the problem is real. Another option is to calculate the resistance if placing two LEDs in a parallel

circuit. With using mathematics as a real tool, the pupils could be free to choose the number of LEDs and batteries when designing badges and other electronic devices. That is demanding, but could be a task for the more skilled pupils.

There was no time for analysing everyday plastic-electronic products (Figure 2).

Another area of natural science principles in a plastazote badge project is chemistry (Table 1). Chemistry was not included in the learning chain in spite parts of two competence aims seem to fit:

The pupil shall be able to

- carry out experiments with and describe hydrocarbons;
- explain how crude oil and natural gas are used.

(Utdanningsdirektoratet, 2007b:9)

The research question for the analysis is:

How could designing and making technological products be a vehicle for enhancing understanding of natural science principles?

Methods and Samples

Analysing practices in ToD education is a new international research area, and so is the development of adequate methodology. ToD in Norway is new and different from other countries (which also differ much, as can be seen in deVries and Mottier, 2007). The methodology has to be tailored for Norwegian ToD practices.

The present analysis includes only three aspects of technology education:

1. Pupils understanding of natural science principles.
2. Stakeholders (pupils, teachers, project groups, headmasters, Department of Education Oslo)

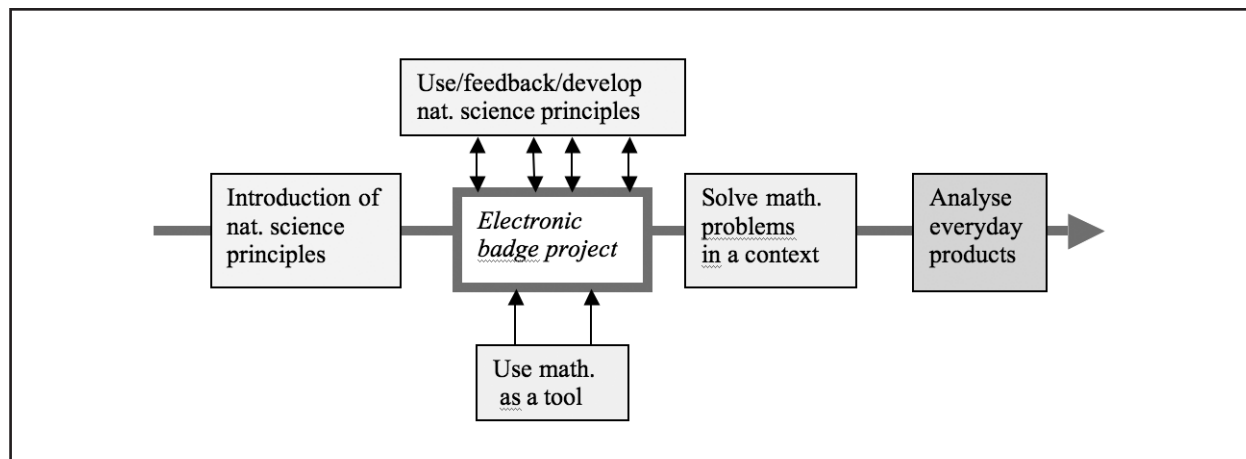


Figure 2. A possible learning chain in an electronic badge project

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[Utdanningsetaten] by LPO documents, Norwegian Directorate for Education and Training [Utdanningsdirektoratet] by KPO6).

3. Teaching approaches.

Several instruments were used:

- Observations (of participants and conversations).
- Interviews (semi-structured, open-ended questions).
- Analysis of pupils' design-portfolios.
- Photographs (sound or video recordings were impractical in this practical project).

In the presentation of results quasi-quantitative measures such as 'all', 'many' and 'few' are partly used.

The population is ca.350 pupils in 14 classes, grade 9 (age 14-15) at three LPO-schools. A convenience sample of four classes was selected (i.e. not randomized, the classes at hand were used) for observations, often including conversations. Concurrent notes were taken, and rewritten immediately after each observed lesson. When finishing two classes at two schools (A, B), it was realised that it was difficult to have good data about individual pupils' skill and knowledge because they always sat in groups when they worked on their individual badges. This was a practical organisation when sharing tools like soldering irons and glue guns. Data collection was therefore extended with interviews at school C to control my observational impressions of pupils' declarative knowledge of the natural science principles which are basic for understanding the particular technological activities in this project. The pre-defined opening questions were:

- 1. Explain how your electronic circuit functions.*
- 2. Why did your plastazote soften when heated and stiffen when cooling again?*

17 pupils, 8 girls and 9 boys, from two classes were interviewed, and the answers were noted in an interview-guide constructed from Table 1. The pupils' answers on the opening questions seldom revealed all her/his knowledge. In this semi-structured interview follow-up questions were used to explore the degree to which they understood and could use the basic concepts named in the competence aims (above): electrical circuits, current, voltage and resistance. Those who 'passed', got following up questions on other concepts they had mentioned from Table 1. A summative judgement of each pupil's answers on both questions was made using the ordinal scale: No – Poor – Some – Good – Excellent.

The pupils' design-portfolios in all four classes were inspected to see if and how they had put in their coupling scheme and other science related descriptions. Some

photos were taken to support notes from observations. During the observations conversations with the teachers also took place. Planning- and evaluation-meetings in each school's project group gave valuable insight into the teachers' interpretation of the given specification and actual competence aims, the implementation of the project, and their impressions of pupils attained skills and knowledge.

Results

The designing and making skills and the badges are not a part of the present analyses, but all pupils completed the soldering successfully, all badges blinked and most badges were skilfully made in good, often funny designs (Figure 3). The pupils at all four schools have all more or less showed themselves to be "able to develop products based on specifications that use electronics, evaluate the design process and assess product functionality and user friendliness" (competence aim above).

Schools A and B have both, according to the teachers and project groups, emphasised the design process at the cost of including science in the project. Of course the teachers had to use and explain some basic concepts from Table 1 to tell why, how and what to do when making an electrical circuit with electronic components and 'baking' a plastazote badge. Conversation with the pupils during the design and making process revealed that most of them demonstrated only rudimentary knowledge in electricity recalled from earlier instructions, not the same 'fluency' in using the right concepts as most pupils in school C. In spite of emphasising designing at A and B, the pupils demonstrated no knowledge of chemical and physical characteristics of the materials. (Neither did C.) The impressions from conversations are consistent with the impressions from examining the design-portfolios and conversation with their science teachers and the project groups' evaluation of the badge project. To sum up: It seems that few pupils at school A and B have reached the competence aim to "be able to explain results from experiments [make the circuit] with electrical circuits using terms such as current, voltage, resistance" (above). Not surprisingly since A and B did not focus on that competence aim. More alarming is that no one could to some depth "describe characteristics of materials [components, plastazote] used in a production process" (above). One of many tasks in a design process, which A and B emphasized, is to choose materials from knowledge about their characteristics. In this project the materials were given, but some material knowledge was expected.

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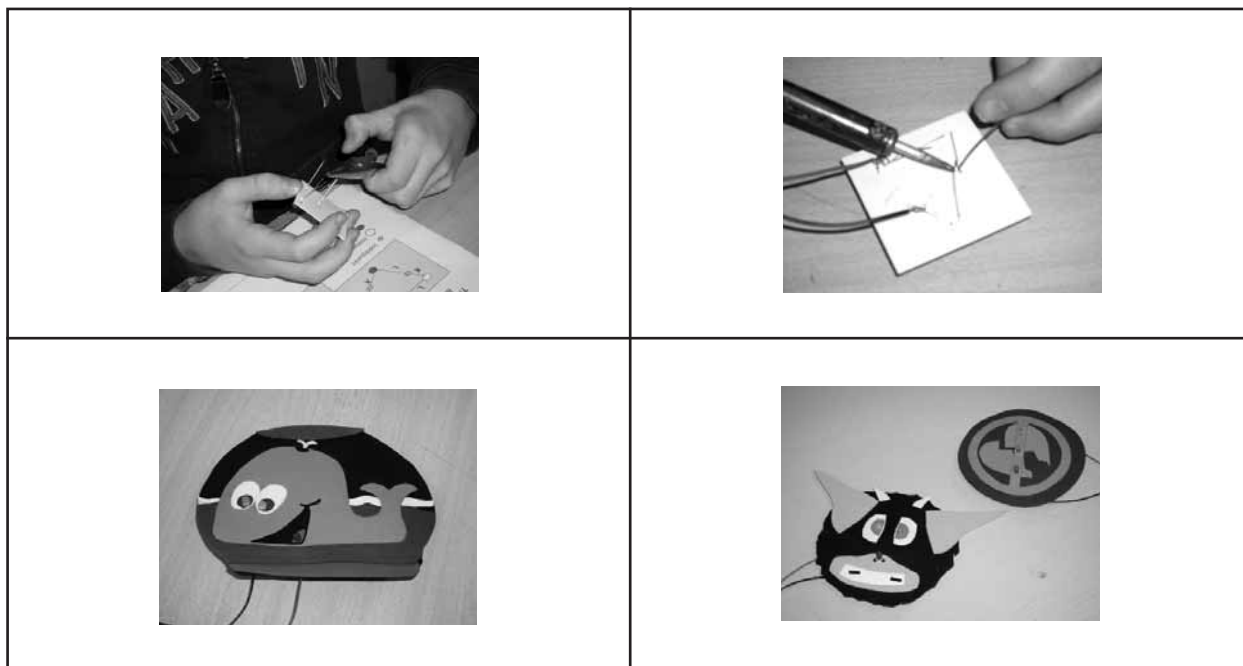


Figure 3. From making and soldering (top) and complete badges (bottom)

In C many pupils could use basic concepts in a theoretically right way when discussing solutions of making the electronic circuit for their badges. The interviews confirmed the impressions. More than half the pupils (11) demonstrated good to excellent understanding of electrical circuits and the function of the components. Most of them knew the difference between current and voltage. They were fully “able to explain results from experiments [making the circuit] with electrical circuits using terms such as current, voltage, resistance” (above). To some depth they “are able to describe characteristics of materials used in a production process” (above), but only electrical and electronic components, not the plastazote. Less than half (6 pupils) were on the same low level that most pupils in schools A and B demonstrated during conversations. Very few (2) of them (in C) had only poor or no knowledge.

The sample in this study is small, and this is a single science topic. It is impossible to compare results in C directly with other studies. However, we know from PISA 2006 (OECD, 2007:20, Table 1) that 78.8% of Norwegian pupils aged 15 performed at or above the demarcation level for scientific literacy: “students start to demonstrate the science competencies that will enable them to participate actively in life situations related to science and technology” (ibid.:21). In C 15 pupils (88%)

reached levels ‘some’ – ‘good’ – ‘excellent’ on the first question. They are judged ‘partial scientific literate’ according to the PISA demarcation used on this topic. Norwegian PISA results split on different topics, show pupils perform better in biology and geosciences than on physics/chemistry (Kjærnsli et al, 2007:66, Figure 3.5). On the background of PISA results it is fair to say that the results at school C were relative satisfactory on electrical circuits with electronic components.

On the chemistry question, no one showed ‘good’ to ‘excellent’ knowledge at school C. Common answers were like: “The plastazote is nearly melting when heated and then cooling back to shape again”. They could hardly say anything about what happens inside plastics when ‘melting’. Words like ‘atom’ and ‘molecule’ were not used. Very few knew what plastics are made from. Hardly anyone reached ‘partial scientific literate’ in this chemistry area.

International PISA 2006 (OECD, 2007) found that “most males were stronger at *explaining phenomena scientifically*. Males performed substantially better than females when answering physics questions.” (ibid.:3-4). Norwegian boys perform better in geosciences and much better in physics/chemistry than girls (Kjærnsli et al, 2007:71-72, Table 3.3). That is not the fact in school

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C on the first question. Here the gender difference is small, but slightly in favour of girls when explaining their own circuit (girls' median is 'good', boys' median is between 'some' and 'good'). It is not possible to rate the gender difference on the second question.

Conclusions and Implications

The badge project demonstrates areas of technology where the interaction between natural science and technology is obvious. The project fits well into a learning chain (Figure 2). The natural science principles in electricity, electronics, plastic chemistry and energy use could be developed and easily used in this practical context, with potential to give positive feedback and further knowledge development. The difference between A-B and C about electronic-circuit-knowledge could be due to the design of the badge project where in C the project was put in the science learning chain, while A-B focused on design. The plastics-chemistry-knowledge was not included in the chain, and the results in C did not differ from A and B. The continuation of the badge project's learning chain could be analysing some everyday products made of plastics covering electronic and electrical systems. This could also lead to some environmental and consumer political discussions in the classroom. With such a continuing teaching approach, the badge project could have been a contribution to development of some conceptual technology knowledge ("knowledge about technology", Dakers, 2007:125), and not only development of procedural knowledge in designing and making and declarative science subject knowledge. "It is as a result of the syntheses of procedural and conceptual knowledge development that technological literacy can be developed" (ibid.:126). The badge project however, was designed only to be a limited project which could fulfil LPO's "focus on results and teaching practice in Natural Science and Mathematics" (*op cit*) guided by KPO6's description of ToD: "Natural science principles constitute the basis for understanding technological activities" (*op cit*).

A small population and small samples, limited examinations and experience from only one ToD-project, limits the possibility to generalise. But, it seems that designing and making useful technological products could be a vehicle for enhancing understanding of natural science principles if the pupils get the opportunity to develop and use science in a technological context. By including learning about technology in the learning chain, ToD projects also could be a vehicle for enhancing

technological literacy. The learning-chain-principle is only one possible approach for good ToD teaching.

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