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The role of research and development to improve STS education: experiences from the PLON project

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This paper outlines four stages of a research–development cycle based on experiences with a Dutch physics curriculum development project (PLON), in which STS aspects are integrated. Through examples it is illustrated that research on first and second version materials is essential, but its value should not be overestimated. The authors are convinced that STS education also needs in-depth research studies in order to survive. Two important topics are mentioned. One is the legitimation of specific contents (scientific concepts and personal and social contexts) of STS curricula. The second topic regards lay-ideas on those scientific concepts that are seen as important for pupils' use in personal and social contexts. As an example a current research–development programme is described that deals with learning to assess the risks of ionizing radiation.

Introduction

In numerous articles in the last decade it has been argued that science education should pay more attention to the science, technology and society interface. Yager (1983, 1984) even defines science education as 'the discipline concerned with the study of the interaction of science and society – i.e., the study of the impact of science upon society as well as the impact of society upon science'. In accordance with this viewpoint he advocates that in order to solve the 'crisis in science education', it would be necessary to develop entirely new science curricula, in which the STS perspective plays a leading role. However, his definition has not been applauded by all of his colleagues in the USA. Kromhout and Good (1983) and Good *et al.* (1985) accept the use of socially-relevant problems as motivation for a coherent study of fundamental science, but reject Yager's definition of science education as in their view it overemphasizes the sociological and political aspects of science education and neglects the coherent structure that is 'the heart and soul of the scientific method' as well as the perspective of learning concepts and reasoning in science. Though they agree that STS aspects should be added to the curriculum, they fear that curriculum units organized around a particular socially-important problem are independent of each other by design and would therefore be unable to convey any real understanding of the structural integrity of science.

Bybee (1987) tried to reconcile the two positions sketched above. He argues that the goals of science education must be reformulated to include both personal and social dimensions as well as the development of reasoning, and favours a 'contextual orientation for the knowledge, process and career goals of science teaching'. He considers it a misperception that the whole of science education will be based then on STS-goals but adds hopefully that 'there is every possibility of students learning more about science and technology because it will be presented and experienced in a context with personal and social meaning'. This belief is common among people who are in favour of STS education and if true would be a strong argument to convince others.

Some authors, who have themselves been involved in STS education for some time, have recently written papers in which they conclude that research that could confirm or refute claims by proponents of STS is missing. Solomon (1987) listed three claims being made by different types of STS courses: the need to differentiate between 'different ways of knowing' (Aikenhead and Fleming 1975), the increase of students' interest in and enjoyment of science, and the possibility of teaching the range of science skills and concepts combined with benefiting from the inclusion of social and ethical issues. She is convinced that we are far from being able to use convincing empirical research to evaluate all these claims.

Rubba (1987) reached a similar conclusion. According to him there is no shortage of position papers singing the praises of pre-college STS education, but these do not provide an objectively-tested knowledge base upon which to make STS educational decisions. Yet already STS educators are being asked by practitioners for 'proof' that STS education will enpower students with certain knowledge, skills and/or affective qualities.

We agree with the urgent need for research on STS claims and in this paper we will describe some of our experiences with this kind of research. Both of us have been involved in developing and evaluating PLON materials. PLON stands for Physics Curriculum Development Project. In this project physics curricula for general secondary education have been developed in which all STS-aspects mentioned have been integrated. These curricula, for pupils aged 14–18 years, are to be used in the regular school system of which a centralized final examination programme is an essential part (Lijnse and Hooymayers 1988). Thus questions concerning how to teach and what to expect from the effectiveness of STS-aspects have played a role in the development and evaluation of these curricula right from the start. Therefore, we think that it is useful to report here particularly about the experience with STS-aspects in the PLON curricula and to reflect on it from the point of view of what it may mean for others working in this field. This paper starts with a brief description of the aims and the development of the PLON curricula. Thereafter we will discuss some of the relevant research findings in various stages of a chronologically ordered research–development cycle. Finally, we will mention our current research studies and argue why this kind of research is required for a further improvement of STS education. It should be kept in mind that the description of the various stages of our work does not mean that this is the only possible way of proceeding. It simply reflects the way in which within a large scale curriculum development project and within the restrictions of a particular school system a major effort has been made to put STS teaching into practice in a worthwhile way.

The PLON project

In conference papers and articles in journals staff members of the PLON project have recently reported about the way in which the PLON project was set up, what its aims were and what kind of materials have been developed (Eijkelhof and Verhagen 1985, Dekker and Van der Valk 1986, Eijkelhof and Kortland 1987, Kortland 1987). Therefore, we can afford to limit ourselves in this paper to a summary of basics.

The PLON project started in 1972 with the purpose of modernizing and updating physics education in secondary schools by producing new curriculum materials. The PLON curricula are meant to replace regular courses in physics; therefore they try to find a balance between preparing students for (future) life roles and preparing students for further education. About 40 units have been produced for junior and senior high schools. A characteristic of the materials is that physics is dealt with in personal, social or scientific contexts that are judged to be meaningful to students. The aim of presenting meaningful physics is partly to increase the motivation for learning by the students (Lijnse 1986) but especially to allow them to use physics in daily life, for example, to interpret media messages, to follow new developments in science and technology, to make consumer choices or to participate in public decision-making. Students are therefore expected to learn many scientific concepts and skills, not just for academic reasons but also to use them in a variety of out-of-school contexts. In various units, though not in all, students are asked to reflect on the impact of science on society and vice-versa, for instance in the areas of electronics, radiation applications and elementary particles research. Some units also deal with the dynamics of developments in science in the past and present. STS aspects are essentially integrated in the curricula, which means that it is difficult to state the percentage of time devoted to STS. It cannot be considered separately from the teaching of physics.

The PLON project ended officially in 1986. However, a number of follow-up activities have been set up, such as the revision of curriculum materials through the new PLON Association, the translation of some materials into other languages, the construction of new materials for special groups of pupils and more in-depth research studies. In the following section, however, we will first deal with research as it was performed during the PLON project period itself.

Research concerning first versions of PLON units

Most research by PLON staff members during the project period was aimed at improving the quality of the units in response to curriculum writers. Methods used for this purpose were questionnaires for students and teachers, meetings with teachers, class observations and interviews with students and teachers. It was learned by experience that the success of a unit could not be measured properly with a first version of the unit. In our view this was due to three reasons.

The first is that the curriculum writers wanted to include a lot of innovatory aspects in the unit; many of their ideas were still ripening during the writing and appeared therefore to be insufficiently mature in the first version. Writing complete educational units in which physics is integrated in a particular context proved to be a difficult task. Secondly, the units appeared to be very innovative for teachers. Equipment was not available in sufficient quantities or did not meet expectations. Teachers felt insecure with the new materials as some topics were brand new to them and some units required teaching methods with which they were not familiar. Above all, teachers did not know what problems they could face with the new materials regarding difficulty, time and practicability. Some reported that they felt like beginners. Finally, for many students the units appeared to be rather strange: they had to do a lot more reading than they were used to in physics lessons, the boundaries with other subjects were not so clear any longer, they had to do more practicals of an open nature and had to report about their findings to their peers. In short, in a number of cases the students got confused by the learning requirements in PLON lessons, which differed in most schools considerably from what they were used to in other subjects or in previous physics lessons.

Some of the evaluation findings above in the primary evaluation stage are of a general nature and might also be applicable to any other major innovative curriculum. It is possible, however, to be more specific about findings related to STS aspects in particular.

One lesson that we learned as curriculum developers is that, in general, issues were dealt with too broadly. We were seduced in our first version materials in trying to deal with a complete issue, such as the Energy Problem or the Nuclear Arms Race. Each of these issues is very broad and complicated and requires a great deal of background knowledge, including a familiarity with various ways of knowing (Aikenhead and Fleming 1975). It meant that the physics easily became dominated by other, scientific and non-scientific, aspects. A central problem appeared to be not only the balance between the physics of a unit and its issue-related aspects, but also to develop a structure in which both do fit together in a really functional and organic way. Also, teachers felt insecure as they were not familiar enough with the issue as a whole and were, as a consequence, inclined to concentrate on the well-known physics parts and to neglect the rest. Consequently, for the revision of the units we decided to limit the issues by decreasing the coverage of non-scientific aspects and, secondly, by developing, after long discussions between the curriculum writers, an improved basic unit structure in which the issue-related aspects and the physics were much better adapted to each other (Eijkelhof and Verhagen 1985).

In our view each unit has to be based on a central question that is really relevant to students. This central question should be presented in the orientation of the unit to draw students' attention to the potential usefulness of what follows. The central question also acts as an organizer for the following series of lessons. It determines the knowledge and skills that have to be taught in order to allow students to find answers to the central question and therefore acts as a selection criterion for the physics contents. In the last part of the unit the central question turns up again in order to provide an opportunity to practise and reflect upon the use of physics in, for example, coping with a consumer decision or a socio-scientific issue, depending on the kind of central question.

A final problem due to the STS characteristics of the units was the tendency among curriculum writers to concentrate on the content of the unit by studying general literature about the issue involved. So much literature was available and had to be studied that too little time was left to pay proper attention to concept development and student activities. This is not meant as an accusation of those writers; it only reflects the general fact that developing issue-related teaching materials requires so much knowledge and experience of such a broad nature that physicists and physics educators simply cannot be expected to have this available without further study.

The general outcome of first version evaluation was the clarification of a number of problems regarding the contents and structure of the units which, in our view, may be characteristic of much more first version STS materials. These problems would cast a shadow over any serious attempt to evaluate learning outcomes of specific units, let alone to assess overall curriculum effects on students. This kind of research has to wait for revised materials in which problems due to the necessary learning process of the curriculum developers themselves have been eliminated. The main function of first version evaluation results is precisely to guide and stimulate this learning process by indicating what kind of problems need to be solved. In our view this applies particularly to developing STS materials, which involves so much with which physics educators are usually themselves unfamiliar.

Research concerning second versions of PLON units

Second version research was of a two-fold character. First, it was aimed at establishing whether the development problems described before had been solved satisfactorily. This was done by a standard unit evaluation procedure that had resulted from the first stage research. As explained above, this was necessary as a prerequisite for the evaluation of more fundamental aims, particularly those related to STS claims. This second type of research applies both at the curriculum and the unit level.

At the curriculum level we wanted to get indications of possible overall increased student motivation and improvements in cognitive learning outcomes, in particular as compared to 'traditional' teaching. In our educational system such results are badly needed in order to make innovative curricula like ours acceptable for larger numbers of teachers and for policy makers who are able to influence examination programmes. At the unit level we wanted to know more about specific learning outcomes as we aimed at a better use of scientific knowledge in a variety of daily life contexts.

In general the second versions were of a much higher quality. Many of the first version problems had disappeared, for example, the use of over-simple ideas by the curriculum writers, the abundance of scientific and non-scientific aspects, the lack of proper student activities, managerial problems and the unfamiliarity with contents and teaching methods on the part of the teachers.

A first indication of the better quality of the revised units was that some units that were highly criticized by students on the first version became rather popular in the second version. An example of such a unit is *Traffic* (Van Genderen 1985), a senior high school unit in which mechanics is taught in the contexts of traffic safety and fuel saving. About two-thirds of the students seemed to dislike the first version. Two years later the second version appeared to be one of the most popular units. No changes had been made to the main ideas of the unit, but the instructions to the activities were better, the main scientific concepts were better introduced and a collection of test questions on traffic situations was included.

A second indication for the improved quality was a less significant difference in performance and preferences between the classes. This might be explained with the arguments that the confusing first versions demanded more from the teachers in terms of clarification of what was expected and/or that teachers felt more at ease with the units after having taught them before. At the curriculum level various studies were done. Jörg and Wubbels (1987) have reported about this for one of the senior high school curricula. Popular units seem to be those that indeed relate physics to daily life or specific interest areas of students, for instance the units *Traffic*, *Music*, *Weather Changes* (boys) and *Ionizing Radiation* (girls). Students seemed to be less fond of units that are either mainly theoretical or mainly technological, such as *Matter*, *Energy and Quality*, *Electronics* and *Electrical Machines* (girls).

In general, students appeared to appreciate the physics lessons with PLON materials. They were especially positive about the student activities and the applied character of the physics. According to them these characteristics should get even more attention.

A second important aspect to be studied at curriculum level is the achievement of PLON students compared to others. This aspect is more difficult to study as the aims of achievement between PLON and traditional curricula partly differ. Some studies in this field are still in progress. So far no important differences have been found in cognitive achievement between PLON and non-PLON students (Wierstra 1984), in spite of large differences in learning environment. In general, PLON students experience their learning environment as more open, varied and differentiated than non-PLON students do. This may be considered as a positive result as PLON students also judge the difference between their actual and their ideal learning environment as considerably smaller than non-PLON students do. Also no difference was found when comparing the performance of groups of students on the same traditional high school examination questions. As traditional education is fully aimed at these examinations one could provisionally conclude that PLON students are at least not harmed in their preparation for further studies and in addition may have gained some extra learning outcomes. As stated above one aim of the PLON project materials was to promote the ability of students to use physics knowledge in daily life situations. The revised versions seemed to be of sufficient quality to examine whether this ability of students was influenced by education. This kind of research was performed in the areas of mechanics (units *Traffic* and *Traffic and Safety*), energy (unit *Energy and Quality*) and radioactivity (unit *Ionizing Radiation*). As an example we describe the results regarding the latter, very popular, unit.

The central theme of this unit (PLON 1984) is the acceptability of risks associated with applications of ionizing radiation. Therefore the unit not only deals with relevant concepts of physics, but also with the effects of ionizing radiation and methods of risk assessment.

In our evaluation study (Eijkelhof 1986) we presented to the students some controversial statements regarding applications of ionizing radiation, before and after using the unit. The students were asked to comment on these. Two examples of these statements were:

1. The disposal of radioactive waste in the sea is not very serious.
2. Food which has been irradiated by a radioactive source in order to preserve it should be banned in The Netherlands.

These statements dealt with contexts that were not included in the unit *Ionizing Radiation*. Therefore, students' answers could not simply be copies of ideas presented in the unit. In the comments on statement (1) hardly any physics was used. Most of them disagreed with the statement, before and after the unit. Arguments were mainly of a common-sense nature and did not change essentially. Comments on statement (2), however, showed more use of scientific concepts in the arguments. This may be explained by the fact that waste disposal is a much more widely-discussed issue in Dutch society. Students already have an opinion about the topic; in that case, for them, the topic of radioactive waste is not a problem so why should they apply any physics? Analysis of the student responses also showed that students seemed to have ideas about radiation that are not in accordance with scientific ideas. For example, we found students using the term 'radiation' where an expert would use 'radioactive substance'. As we detected these lay ideas both before and after the unit we expected that students had gained these ideas on radiation outside school.

Similar results were obtained from evaluation of the units *Energy and Quality* and *Traffic*. Research on these units did show that pupils were partly able to apply their knowledge in real-life contexts, though at the same time it directed our attention to a perspective that had got insufficient attention in the development of the materials. We are referring here to what has become known as 'the alternative framework movement', which seems to be of particular importance to our interpretation of STS education. Our findings are best described by the distinction made by Solomon (1983) between life-world domain and symbolic domain, based on the phenomenological description of the life-world by Schutz and Luckmann (1974). In Solomon's view 'adolescents are continually being socialized into a whole repertoire of non-scientific explanations', which are often experienced as completely functional within their daily-life contexts. We realized that this might especially prove to be a challenge for STS education as by its very nature it does not allow students and teachers to operate in only one of the two domains. Without clarifying the relation between these two domains STS education might not succeed in achieving one of its main aims. The curriculum writers had not paid enough attention to this aspect in constructing the second versions, occupied as they were with selecting issues, scientific concepts, contexts, student activities, unit structures, etc. They had assumed that presenting relevant scientific concepts in various contexts would be a sufficient base for using these concepts in out-of-school life.

In summary, regarding evaluation of the second version units we could conclude that, although the units appeared to be received much better by both students and teachers and to reach their goals to a reasonable degree, we could not be satisfied about the way in which the problem of the relation between life-world domain and symbolic domain was being treated in our teaching materials.

A third stage of research

The evaluation of the second versions indicated two main problems related to STS teaching, but did not suggest solutions. The first of these problems is especially relevant if the teaching of school physics is determined by a centralized syllabus and examination programme. Teaching physics within relevant daily life and issue-related contexts means that the disciplinary structure of physics is no longer the only sufficient guide for selecting curriculum content, while the choice of contexts also needs further justification.

Acceptance of new concepts and contexts in a national curriculum asks for a much broader legitimation than can be provided by curriculum developers alone. Acceptance and legitimation can be considered as a prerequisite for a successful innovation. In our view such legitimation applies particularly to STS aspects of a curriculum. The second problem has to do with the development of adequate teaching and learning strategies that explicitly take into account the particular STS aims in relation to conceptual learning problems that result from differences between the life-world and the world of physics. These differences also ask for a fundamental rethinking of those aims themselves. Both problems ask for a new research and development effort of a much more in-depth type than we reported above. So far it has only been possible to apply such a research effort to exemplary case studies centred around certain topics. As an example of our 'third stage' research some more details will be given now about such a case-study on the topic of ionizing radiation.

As stated previously, we detected some student ideas on ionizing radiation but we did not know how common these are. A study of the literature shows that hardly any publications deal with this topic. Also, little is known about the way people communicate, personally and through the media, concerning radiation issues, though such communication might be an important source and reinforcement of student ideas. From an STS viewpoint just correcting all lay ideas would not be wise as the use of knowledge in real-life situations should be the main aim of our teaching. But then, which real-life situations would be most important? Finally, what would be an appropriate learning strategy to promote the use of scientific knowledge and skills in daily life, taking into account lay ideas, appropriate contexts and concepts?

To this end we started a research programme in April 1986 aimed at gaining insight into how physics education could make a contribution to students' ability to assess the risks of applications of ionizing radiation. It seemed appropriate to approach this topic from various angles:

1. Consulting radiation experts with the main aim of legitimating contents and assessing the importance of specific lay ideas. Through a three-round Delphi study we extracted from about 50 radiation

experts information and opinions about suitable contexts and contents for physics education, about the perceived occurrence and importance of a range of lay ideas, and about advisable ways of dealing with fear of radiation in class.
2. Studying newspaper reports as possible sources and means of reinforcement for student ideas. In this way we hoped to elucidate the implicit meanings given to words such as radiation, radioactivity, half-life, dose, dose-limits, irradiation, radioactive contamination, etc. and the misunderstandings in which these lay ideas would result.
3. Interviewing students about their ideas on various radiation contexts, such as nuclear waste, Chernobyl, food irradiation, health radiation and natural radiation, and about the meanings of radiation terms.

Thus, having broadly legitimated the choice of concepts and contexts to be taught and having mapped out the life-world way of thinking and reasoning about matters of radiation within those contexts, a new teaching unit is to be developed in which an improved teaching strategy will be tried out which, we hope, will be more successful in reaching our STS goal of bridging the gap between the world of physics and the life-world in a really functional way. Already plans are being made to start the fourth stage of research, which, not surprisingly, will consist of an evaluation of the third version of the unit.

Conclusions

In this article we have outlined a long-term working strategy in which development and research activities are closely tied. One could easily argue now that we should have planned in advance the kind of research that we categorized in stage three.

However, this would be too easy a reaction. Our description reflects a process of 'learning by experience' within a large-scale curriculum development project that tried to reach rather innovative STS goals. Because of the novelty of these goals and the scale of the project such a learning process was necessary and unavoidable.

Apart from this our description also shows a development in the type of research questions that reflects the time-scale of the project. Initially, evaluation was primarily seen as an assessment of achievement in relation to objectives. Now we perceive that research is necessary to dig much deeper into conceptual learning processes. In our case, however, we have tried to describe how these two developments have reinforced each other in a cyclic process, aimed at developing, improving and understanding STS education within a complete physics curriculum.

The ties between research and development seem to have several functions. First version materials can show what is meant by authors of position papers, but, in general, their quality is probably not good enough for final evaluation. First stage research does give feedback to writers about how to construct better units, but should not be used to claim the ultimate success. Second version materials could be expected to be of much better quality and therefore to be useful as objects for second stage research, at unit and curriculum levels, in order to study some claims, for example claims about motivation and cognition. Through such research some of the real problems of the materials could be traced and clarified. From this latter type of research one can expect only directions for improvement, not clear guidelines. To formulate these we believe third stage research of a more fundamental nature is required. Only after that would it be worthwhile rewriting materials in order to evaluate their effectiveness.

In our view third stage research is crucial for the future of STS education. It should include a broad legitimation of contents and criteria for selection of contexts and concepts. External experts should be included in this procedure and their advice should be taken seriously. Otherwise STS education might face several disasters: falling prey to the whims of its practitioners (Rubba 1987), drowning in its abundance of contexts, concepts and other aspects (compare the STS Block J Science Syllabus for Middle and Junior High Schools for the State of New York as reported by Bell *et al.* 1986) or being rejected as dealing with unimportant and/or obsolete issues. Second we recommend proper attention to lay ideas on scientific concepts, in order both to select those to which STS education should pay attention and to develop strategies for dealing with these ideas. We prefer not to call them children's ideas in science (Driver *et al.* 1985) as many of these ideas are not confined to children but are part of the stock of social knowledge. Of course, this recommendation applies to physics education in general, but if STS education is integrated in the regular physics curriculum, the specific objectives of STS education make the problem of how to deal appropriately with lay and scientific ideas the very heart of the matter. Co-operation with those working in the field of preconception research might be fruitful in this respect.

The points we make above are essential in two respects. First, the survival of STS education in the long run will depend on its credibility with scientists, science teachers, parents, students and policy makers. Good intentions and enthusiasm are essential for making a start but will not be sufficient in future to influence science teaching in our schools. Second, and most importantly, if we want to raise the quality of our STS teaching in order to increase the number of well-informed citizens it is our duty constantly to improve our efforts by reflecting on our experiences and by being willing to revise our education. In that respect research and development need each other.

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