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published in
Research in Science Education - Past, Present, and Future
2001

DOI (link to publisher)
10.1007/0-306-47639-8

document version
Publisher's PDF, also known as Version of record

Learning About Investigations - The Teacher's Role

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Abstract

A group of Dutch physics and chemistry teachers have been co-operating since 1997 in the development of pupils' investigative skills. We studied how much attention investigative skills received when these efforts started. Practical tests were designed to develop investigative skills, that previously received insufficient attention. This paper discusses the existing teaching practice and the classroom trials of these practicals. Conclusions are given as a tentative plan, specifying how fostering the development of investigative skills can be incorporated in physics and chemistry teaching.

Research question

The curricula of higher ability streams in Dutch secondary education are under reform. In the new programme pupils have to demonstrate their mastery of 'investigative skills' in science subjects and learn to conduct scientific investigations. This aim is not new (Hodson, 1992; Tamir, 1989), but views still diverge as to what is to be learned and how it is best taught. The exam programme implies that 'being able to conduct an investigation' is equivalent to mastering a set of investigative skills, a view similar to the views expressed in, e.g., Lawson (1994) and Klopfer (1990). However, the claim that 'investigative skills' can be identified and distinguished from each other, from other knowledge (e.g. common sense knowledge) or from other skills (e.g. technical skills) is not a claim we believe to have been adequately tested at this point.

Together with teachers, we designed learning activities in physics and chemistry to teach pupils about investigations. The activities were used in class and evaluated. This paper discusses the first explorative phase of our research, directed at mapping the teachers' teaching prior to the new exam programme. We construct this map by answering the following questions: To what extent was the development of investigative skills an educational aim in physics and chemistry prior to the reform? How is that reflected in actual teaching and learning? What views and plans do teachers have in order to foster 'learning how to carry out investigations'? and what kind of support, if any, do teachers need in that area? The answers led to a plan of action that is a compromise between aims and experiences of teachers and our (preliminary) insights regarding an effective educational strategy for learning about investigations. The next stage of our study involves a classroom test of the plan.

Research Method

The network

In September 1999 all schools have introduced the new curriculum. Our study was carried out in a 'network' where preparations were made for this educational reform. In this network, teachers of chemistry and physics of five schools cooperate

H. Behrendt et al. (eds.), Research in Science Education – Past, Present, and Future, 325–330.

with science education specialists of the 'Vrije Universiteit' in Amsterdam. The rationale for this cooperation is that teachers can develop new teaching practices more efficiently if they can make use of each others' expertise and the support of an educational specialist. Premises guiding the network are:

1. Changes in existing teaching practice may take place if the teacher sees these as desirable, feasible and possibly fruitful in the light of his existing teaching practice.
2. Pupils learn how to investigate by doing investigations.
3. The theory of an educational strategy for 'learning about investigations' will form and grow in the process of: formulation of an educational aim(s) – design of materials – classroom trials – reports - evaluation - adjustment of aims etc.

The first meetings involved an exchange of views regarding the first premise. When agreement was reached about aims and approach, activity shifted towards the third premise. Consensus existed from the start about the second premise, which is why 'investigative' practicals recieve much attention. Network meetings occur bimonthly. Reports, based on letters, transcripts or notes of the meetings, provide information on the development of aims and approach. (The documents of this study were translated into English by us.) Of these reports, a summary was made focusing on:

1. Aims and views of the teachers regarding investigations by pupils;
2. Teachers' approach to designing and implementing investigative practicals;
3. Experiences during trials of investigative practicals;
4. Evaluation of the activities within and of the network itself.

Inventory and interviews

Teachers produced an inventory of the practicals in their teaching (Tamir, 1989) by listing which investigative skills their pupils practised prior to the new programme. To carry out an investigation, pupils must have the necessary theoretical and procedural knowledge and apply it correctly at the right time. Typical for investigations is that actions of a particular kind are executed. Some of these 'investigative' actions are of a physical nature, but most actions, and the most important actions, require a mental performance. These actions can be grouped in the following 'phases', present in many, but not necessarily all investigations:

A. Develop aim of research	D. Collect data	G. Draw conclusions
B. Plan analysis of data	E. Work out results	H. Report
C. Plan collection of data	F. Interpret results	

Each phase consists of several investigative actions. For example, phase F consists of: (1) explain phenomena; (2) interpret properties of graphs; (3) compare results with other sources; (4) discuss accuracy and precision. This list, used in both subjects and based on Feiner-Valkier (1993), is just one of many that can be found in the literature. However, it is constructed with the teachers as a list they find adequate. For each practical and stream, teachers noted which action received attention and specified whether pupils carried it out under guidance or independently. To provide a background for the inventory, the teachers answered questions about the role of investigative actions in their teaching.

Teachers were asked whether the list of investigative actions was adequate and complete. They were asked for their views regarding the educational aim of developing investigative skills. LvR interviewed 5 chemistry teachers, PD 5 physics teachers. Each interview lasted from 1.5 to 2.5 hours. The interviews were transcribed and summarised. Relevant statements were added verbatim. Finally, some of the lessons during which teachers tried out the investigative practicals were attended by us. Illustrations from these lessons are used in this paper.

The teachers

All teachers teach age-groups 16-18 and have at least 5 years of teaching experience. We observed differences between subjects, teachers and schools especially regarding views about education, educational aims, approach and innovation-mindedness. From experiences in in-service courses and workshops we conclude that our findings, plans and approach are useful to at least a certain group of physics and chemistry teachers.

What is 'carrying out an investigation'?

Our view on 'learning how to investigate' formed gradually and then influenced the network activities. Here, we do not discuss the literature that contributed to it. The account given below shows how this view was used in the network.

Pupils have a certain investigative skill if they can execute with success the specified investigative action at an adequate level. 'Success at an adequate level' is determined by the theoretical and procedural knowledge the pupil is expected to possess. Applying knowledge to actions requires that links between knowledge and actions are established and maintained. The pupil can establish and maintain these links by posing, at appropriate times, the following questions regarding his actions:

1. What am I doing? (What have I done? What shall I do next?)
2. Why am I doing this? (Why did I do this? Why should I do this?)
3. How can I do this differently, better?

These questions provide only a pattern, they have to be adapted to the various investigative actions before the answers can guide pupils' further actions. A teaching practice in which pupils develop investigative skills is one, we believe, in which they ask themselves questions derived from the three questions given here and learn to use the answers. Acting in accordance with the answers means guarding and optimising the quality of the investigation, a quality which is reflected in the validity and reliability (Millar, 1994; Smits, 1995) of the outcomes.

Findings

Current teaching practice

The teachers in this study regarded the list of investigative actions to be adequate. In the inventories the difference in numbers of practicals is striking, varying in physics from 3 to 26 over the course of 3 years. The inventories also show that during practicals, pupils are chiefly involved in the phases D, E and F of collecting, representing, manipulating and interpreting data. Phases G and H, drawing conclusions and reporting, receive less attention.

Phases A, B and C, of phrasing an aim and planning the investigation, are hardly ever carried out by pupils on their own. During interviews, teachers gave as reasons: 'I just follow the textbook'; 'the current exam program does not really demand it'; 'I am not familiar with pupils carrying out investigations.' A lack of time, adequate teaching materials, technical assistance and laboratory space are mentioned as additional hindrances. The teachers feel that, to start investigations at age 16, pupils should have skills related to reading, writing, arithmetic, measuring, processing data and writing reports.

Teachers' aims and plans

Teachers consider the development of pupils' investigative skills to be a relevant educational aim. About the new exam programme, they say that 'the demands are clear, but how to teach pupils these skills is not'. The teachers believe that practicals can teach pupils to be conscious of the relevance of their actions, to learn how to think logically, to discuss with and consult each other, to improvise and to experiment. Most teachers do not want to increase the time spent on phases D, E and F and doubt whether there is enough time to address the other phases properly. The teachers plan to follow a systematic approach, gradually increasing the independence and quality of the investigations. As a first step in working towards this aim, the teachers expanded their existing practicals by letting pupils carry out the planning of investigations.

In the first network meetings, plans were made to (re)design investigative practicals in accordance with the teachers' aims and experience in investigative tasks. In these practicals, pupils were to be given more freedom and responsibility in the design and execution of investigations. Teachers wanted the practicals to relate to the theory concurrently discussed in class ('recognisable for pupils'), to have a size of 2 or 3 periods ('small scale changes') and to consist of complete investigations ('otherwise motivation is lost'). Teachers wanted the practicals to relate to the pupils' “lifeworld” knowledge and 'intellectual capacity' ('so the pupils remain motivated'). They wanted to monitor and assess the investigations by using pupils' plans and reports.

This approach resulted in nine (chemistry) and eleven (physics) investigative practicals. Design, trials and adjustments of these practicals are time consuming; the focus remained on year 4 (age 16).

Experiences in class

Dekkers and van Rens (1999) have reported the classroom experiences. Here we only outline the process that teachers went through during trials, evaluation and adjustment of the practicals. Before the trials, teachers expressed concerns; 'Will they find the tasks to be sufficiently challenging?'; 'Will they enjoy it?'; 'We should make certain that they can obtain some results'; 'The experiment should function properly, I will ask the technical assistant to check it first.' In class, these concerns were allayed. The pupils were enthusiastic and engaged, responding creatively to questions like: what will you investigate, how will you do it, what do you need to do so? These matters were evident in the pupils' plans of operation. The teachers then turned to the problem of handling differences in approach and quality. Unsafe plans were dismissed. However if plans are of a poor quality, should pupils be allowed to run into trouble, or should guidance be given? The teachers decided to suggest improvements to the plans and give the pupils time to discuss these. As it turned out, the pupils made hardly any use of these suggestions. As one pupil proudly remarked: 'Our plan is simply the best in our class.'

During the experiments, many pupils learned that experiments can turn out differently from expectations. This usually caused them to focus on technical details, while the teachers mainly helped pupils overcome their uncertainties.

The pupils wrote individual reports of the chemistry practicals. In these reports some pupils attempted to explain what they had observed, but did not relate this to their research question. Others did remember their research question, but adjusted it so that their observations could be used to answer it. The teachers noticed this, but did not go into the matter during discussions of the reports. The teachers indicated that they did not yet know how to deal with this issue, it will require attention in the future.

The teachers agreed that it was important to focus on pupils on describing their investigative actions, on the quality of these actions and on improving this quality. Yet they often failed to do so. For example, when the pupils did not improve their plans, the teachers tried to stimulate external (referring to e.g. the height of marks) rather than internal motivation (by making pupils see the point of a good plan). Pupils were not urged to draw explicit conclusions about investigative actions (e.g. by answering the question: How can I plan better next time?). It was unclear whether pupils learned things which could be carried over to future investigations.

At present, we cannot show that improving teaching requires, paying more explicit attention to investigative actions. However, some experiences suggest that we are on the right track. For example, one chemistry teacher noticed that stating the importance of planning the approach and formulating expectations had no effect on the quality of the plans. He then decided to have pupils account for their chosen approach and formulate their expectations as a regular part in their reports of investigations. His pupils, who did three investigative practicals within two years, clearly improved in choosing a reasoned approach and specifying expectations.

When teachers attempt to focus on investigative actions, a balance must be found between the extent to which pupils are left to resolve their problems and the time given to do so. Another question is how much practice pupils need to acquire a skill before mastery of the skill is assessed. To answer questions of this kind, we need more experience with activities in which investigative skills are the *explicit* aim.

We see that once teachers gain experience and insight in one area, a new concern surfaces. This process has not yet ended. Several teachers question the outcomes of learning in this area as compared to the invested time and effort. They put justifiable demands on investigative practicals.

Main conclusions

The teachers in the study are prepared to pay more attention than before to 'learning about investigations'. They all designed and implemented practicals for this purpose. They feel that 'learning how to do investigations' is an educational aim that fits science subjects. They actively adjust their teaching to provide a place for 'learning about investigations' in line with the new exam criteria. In investigations, the teachers pursue a gradual, systematic increase of independence and scientific quality. Teachers think that the best way for pupils to acquire investigative skills is to carry out investigations and to try to resolve their problems by themselves.

To pay more attention to investigative actions other than observing, data handling and representing results, it often suffices to adjust existing practicals. The teachers are developing the skills needed to adjust, design and teach these new practicals. The main worries of the teachers, concern the available time and personal support. How much time do pupils need to solve their problems and how can the solutions be made transferable? The teachers are becoming aware that our knowledge of learning about investigations is still limited. A view of what is required in 'learning about investigations' develops gradually.

We have designed a plan for subsequent research that takes into account several of the above issues. The feasibility and effectiveness of this approach will now be empirically tested. A series of investigations is to be designed for the age-groups 16-17, working systematically towards self-reliant investigations of high quality. Several practicals designed and piloted in the network can be of use in this series.

The series consists of complete investigations. One phase in each investigation is chosen to receive special attention. The skills pertaining to it are specified as aims of learning. This phase is open on the one hand; pupils are given time to experience problems and solve these. On the other hand, it is also guided; pupils are asked to describe their problems and evaluate and compare the solutions.

The remaining phases are either open-unguided or closed-guided. A phase that has received special attention is open-unguided; higher standards are maintained concerning the independent performance and quality. A phase which has not yet received special attention is closed-guided, performed with the class as one team with strong teacher guidance. The most difficult phases of investigations are dealt with last and during the series; a gradual integration of investigative skills is pursued.

This plan of research, which is only roughly outlined here, does not state *how* pupils and teachers can be enabled to make the relevant questions (what am I doing, why and can I do it better?) become the central questions in their activities. We intend to find ways to get teachers and pupils to focus on these questions, on answering them and using the answers. This, however, requires that both the teachers and researchers develop a better understanding of how pupils handle investigations. We will have to determine what pupils learn in practicals, what we want them to learn in investigations, and how we can motivate them to engage in learning this.

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