THE NEED FOR ADDITIONAL LABORATORY EXPERIENCES IN THE PSSC PHYSICS PROGRAMME

Frank Hofmann

A Monograph submitted to McGill University in partial fulfillment of a Master of Education degree in the Teaching of Physics.

Advisor: Professor P. Landry
McGill University
Montreal, Canada

July, 1976

ABSTRACT

When it was noticed that students at the grade 10 and 11 level were experiencing difficulty in coping with portions of the PSSC course of study, extra experiments were designed to eliminate some of the confusion and apathy affecting students. These "extra-labs" were developed over a three year period and given to students in the PSSC course at Beaconsfield High School in Beaconsfield, Quebec. The extra material consisted of experiments and demonstrations on the same topics as the regular experiments, but were on a more practical level.

The reactions of students who were exposed to this enriched programme were evaluated by the author--the teacher involved.

Consistent student enrollment, student reaction, results of questionnaires, and general observation all suggest the programme was a success.

RESUMÉ

Après avoir remarqué que les étudiants de 10ième et 11ième anneé avaient experimenté des difficultés avec portions du cours PSSC, des expériences additionnelles ont été élaboreés pour éliminer quelques confusions et apathies qui affectaient les étudiants. Ces expériences additionnelles ont été développés pendant une période de trois ans et donneés aux étudiants du cours de PSSC à l'Ecole Secondaire de Beaconsfield à Beaconsfield, Québec. Ceux-ci consistaient en des expériences et démonstrations plus practique.

Les réactions des étudiants exposés à ce programme enrichi ont été evalueés par l'auteur (professeur en charge).

La consistance des étudiants, leurs reactions, les résultats des questionnaires, et l'observation générale, tout ce qui fut suggeré dans ce programme a été un succès.

TABLE OF CONTENTS

INTRODUCTION

Educators are concerned with how best to build and alter mental structures. Their goal is to maximize the flexibility of students' minds which have been exposed to a prescribed learning situation.

In the field of high school physics, educators have traditionally taught with the aid of laboratory situations and demonstrations in an effort to promote the understanding and conceptualization of abstract physical relationships. This experimental approach has been necessitated by recognition of the fact that much of what is taught in a high school physics course requires the use of abstract thinking, a process best developed in the student by having him interact with materials, fellow students, data and theory in the process of performing an experiment.

It is the contention of this paper that valuable learning experience can best be gained, however, if the laboratory situations themselves satisfy certain criteria.

Whereas educational theorists generally agree on the pattern of the learning process, one which progresses from basic notion to concrete experience to discovery and then abstractions, it is possible that many educators have in actual practice overlooked this very necessary pattern. It is generally accepted that the pattern works only when the learner progresses through each step

<u>personally</u>, when the experience and the discovery are his own, when the motivation toward each next step comes from within, rather than is imposed from without. He must not only be willing and able to learn, but eager to learn as well. Without this "energized will" to learn no proper learning can take place.

Inherent in the development of this energized will is the necessity first to capture the interest and imagination of the student. Since laboratory situations play such a dominant role in the teaching of physics, as well they should, it is of the utmost importance that they succeed in motivating the student to learn. It is my thesis that if concepts presented by a teacher or the orientation of a laboratory experience are to excite the average high school student and motivate him to learn, they must first prove their applicability and relevancy to the real world, academic and concrete. My premise is that any student going to school expects either consciously or unconsciously to be able to put to use any body of knowledge to which he is exposed in order to help him solve, quantitatively or qualitatively, his life's problems. He expects this no less of physics than of any other subject. It is at this juncture that the orientation of the physics laboratory experiment and the lecturer play a crucial role. A good teacher, as well as a good laboratory situation, should informally communicate the ultimate overriding importance of what is being presented. A good laboratory exercise, or a good teacher, should never cause the question to be raised in the student's mind, "What is the use of all this?". However, many present laboratory experiments--including some designed in the PSSC[1] programme with which we are to deal--do in fact fail to arouse in the student any sense of personal involvement. These experiments appear to stop short of enlisting the student's subliminal element of interest by not showing their investigation's applicability in reality. They leave their investigation isolated at the point where it shows its meaning in physics only, and not in the larger life context. This is detrimental to any real learning process.

This paper will describe some modifications to the PSSC laboratory experiments as they now exist: the philosophy behind the changes, and the students' reaction to them. These changes destroy neither the content nor the structure of the present programme, but rather make the programme real and pertinent to the student, a necessary final step if the student's education in high school physics is to be assured.

---

[1] Haber-Schaim, U., et al, PSSC PHYSICS, 3rd Ed., Lexington, Mass., Heath and Co., 1971.

I

BEACONSFIELD HIGH SCHOOL

The setting for the research on this monograph has been Beaconsfield High School, a large suburban high school in the Lakeshore School Board situated in Montreal Island's west end.

PSSC physics, a lab oriented physics course, was introduced there in the fall of 1971 at the request of the principal who apparently responded to community pressure. At that time Beaconsfield High was the second of five high schools in the board to adopt PSSC, Chem Study, BSCS, and IPS programmes[1]. Students of this suburban school are predominantly university oriented, are the sons and daughters of professional, management, and company-owner parents, and because this board has had the money and personnel to handle a variety of programmes, they have had the exposure to various innovative programmes which frequently appear on the educational scene.

Physics enrollment has been consistently high in this school of 1600 students since 1970. Typically the school offers a choice of four different physics courses in which

---

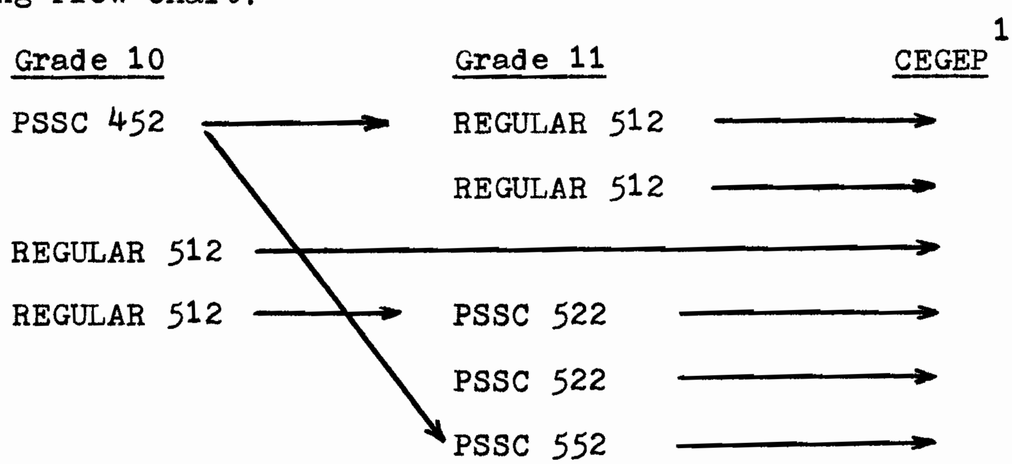
[1] These are all laboratory oriented science study programmes.

PSSC- Physical Science Study Committee, using Haber-Schaim, U., et al, PSSC PHYSICS, 3rd Ed.
Chem Study- Chemistry Study, using O'Connor, J.W., et al, CHEMISTRY EXPERIMENTS AND PRINCIPLES.
BSCS- Biological Sciences Curriculum Study, using Welch, C.A., Supervisor, et al, BIOLOGICAL SCIENCE-MOLECULES TO MAN.
IPS- Introductory Physical Science, using IPS Group, INTRODUCTORY PHYSICAL SCIENCE.

they may enroll. This scheme has resulted in five "regular" classes, and five PSSC classes. Of the average enrollment of 350 students in the grade 11 graduating class, roughly 250--or 70%--will have taken a physics course. This may be compared to West Hill High School in Montreal where the economic background of the student population is in large portion not unlike that of the population in Beaconsfield, but which also draws its students from homes whose parents form the work force in the lower middle class sphere, where 45-50% of the graduates will have had a course in physics. At the same time, according to data gathered by the Quebec Department of Measurement and Evaluation on High School Leaving Examinations, the schools in the western suburban area and specifically Beaconsfield High regularly achieve among the highest average marks on the Provincial Leaving Examinations. (Attempts at providing reasons for this high physics enrollment and for the consistently superior grades achieved in provincial examinations will be made further on.)

There is no overt attempt to select students for physics courses. Whenever possible, students in grades 9 and 10 who are considering taking physics are asked to examine their academic record realistically to ensure that they are willing to carry on, and are capable of doing so, in an academic stream. Similar counselling is given students when they register for other elective courses. It is always interesting to note that whenever students are asked in counselling sessions what it is they think physics is all about, they are very vague; consequently a good part of the counselling consists of explaining to students what a physics course attempts to accomplish. It is obvious to those who counsel that "physics" is a very nebulous thing to them, unlike "biology" or "chemistry". Yet at the same time they do appear to have certain expectations of the programme, as we shall see later upon looking at the student questionnaires.

In an effort to give students maximum flexibility of choice in their selection of an appropriate programme toward their selected goals, certain cross-over combinations are allowed between the four courses offered. Experience has shown, however, that although this option exists, it is rarely chosen. Seemingly students are sure of their choice, and clear as to the significance of their option. The course option is presented and explained to the students with the aid of the following flow chart:



---

[1] CEGEP- Collège d'Enseignements Générale et Professionnelle: Quebec's junior colleges.

In Quebec, the Physics 512 course is the traditional physics course dealing with heat, mechanics, light, electricity, and modern physics, and was, prior to 1971, the only physics course available at Beaconsfield High. It is a one year course and may be taken either in grade 10 or 11. Although it may be taken in either school year, in fact no grade 10 students at Beaconsfield have elected to take the 512 course, with the exception of one or two who have joined the grade 11 512 classes. The PSSC programme offers two routes to the student: one is the PSSC 522 course which sets a rigorous pace and covers all the material in one year--necessarily grade 11. The second route available is PSSC 452 and 552, the two-year grade 10 and 11 course, which allows more "breathing space" between lessons, thus slowing the pace of the course to span two years, but which covers the same material as the 522 course. In this second option wave motion and motion are taught in grade 10, and energy, electricity and magnetism, and modern physics in grade 11.

The programme was set up in this manner because it was believed that the community demanded a flexible and sophisticated programme giving maximum choice to the students, especially in view of the fact that this population is very mobile, with many transfers occurring into and out of the school during the school year. The large choice of options was made possible because the school has been on modular scheduling since 1967. The modular timetable has freed teachers and students at odd times, allowing small groups to get together for varying lengths of time. One result of this has been that laboratory periods in some cases are a whole morning in duration.

Students are advised that if they plan to take science at the post-secondary level they should enroll in either the 522 or the 452-552 programmes, since the PSSC courses are recommended by the CEGEP's. Those students graduating with just the Regular 512 course are obliged to take a "make-up" course in CEGEP before enrolling in CEGEP level physics courses.

Beaconsfield High was expanded in the early 1960's as a comprehensive high school, offering the full range of technical-vocational subjects. However, the tenor of the community or of the student body must have been misjudged from the outset since the sheet metal section was abandoned at the start. Subsequently the electricity and house wiring sections were closed due to lack of student interest. A year later electronics, with its fully equipped laboratory, was closed and the equipment sent to a CEGEP. The small motors lab today is the ceramics shop. Auto mechanics is on the decline. Wood shop is attended primarily by grade 7-9's, and the enrollment in technical drawing has dropped to such an extent that its teacher has had to accept additional classes in the machine shop to fill his workload. The machine shop itself has had half its equipment transferred to another high school--equipment that was specifically of industrial quality: a lathe, a milling machine, a shaper, and a surface grinder. Whereas changes do occur in time in any institution, it seems odd that such drastic cutbacks in the technical-vocational programme have occurred so immediately upon the heels of the implementation of that programme. It would appear that the needs of the school were misread. It is significant that at the same time as these particular declines have been occurring in the school, the same school is promoting and pioneering "industrial orientation" programmes which send students into industry to observe and sometimes work for weeks at a time. This programme appears to be thriving. Since the two programmes seem to be closely related, how can one account for such different responses?

The picture at this school appears to be one of the shunning of the trades. It would seem likely that the occupations and lifestyles of the parents of this community greatly dictate how the students choose their optional subjects. Their choices are based in large part on their expectations of their own future lifestyles. As well, the teachers in this school tend to live in the suburban area with its attendant lifestyle, and therefore may not be ideally suited to teach the technical-vocational subjects. It is improbable that, given both these conditions, these teachers would be able to interest students in pursuing the trades. What remains is a highly qualified and specialized group of teachers, but all oriented toward academia, in full support of the parents' mores. Superimposed on the community's influence are the requirements set up by the province's CEGEP's. These make physics a required course even to enter the health sciences, whereas there are no similar technical requirements, for example technical drawing, for entrance to any of the science or engineering programmes. Given a university oriented body of students, it is understandable that the technical-vocational programme is dieing.

Students sense this isolation or specialization. Whereas social pressures do not permit them to take classes in, for example, small motors, they are allowed to take physics. Perhaps if they can't make a motor work, they can learn why it should work. Seen in this light it is not unusual that the enrollment in physics is roughly 25% higher than in a comparable Montreal school where, as has been stated earlier, the population--though in large part identical to that of Beaconsfield--includes those of a lower middle-class lifestyle. This could also explain why the industrial orientation programme is succeeding where the technical-vocational failed. Whereas the students generally cannot envisage themselves working on a motor as a daily routine, they are interested in how industry in general operates. As future managers and company owners this would seem vital information to them.

Coincidentally perhaps, three out of eight teachers in the Beaconsfield High science department have had direct industry related jobs prior to becoming teachers. This is an unusually high proportion of industry experienced teachers, higher than for any of the other departments in this school as well as for other schools where this was verified. It is possible, though not verifiable in this paper, that student enrollment in the sciences has been influenced in some measure by the kind of added learning and living experiences these teachers are able to bring to their science subjects. It might also, along with such factors as parent background, school board size and its inherent opportunities for flexibility, sufficient funds available for a wide selection of equipment, and so on determine why students from this school have consistently scored among the highest results in the Provincial High School Leaving Examinations. It is not at all unusual for a few or even one teacher to have a measurably profound effect on the growth of his students. This is not, however, to belabour why enrollment and standards have been as high as they have. Investigating these phenomena further is not the purpose of this paper.

Assuming that course enrollment is some measure of community demand as well as of student interest, which in view of all the foregoing seems to be a valid assumption, it is important for a course in physics to fulfill the role of not only being esoteric, to satisfy community pressure, but of also providing for the student and his demands a balanced, real view of the physical world which the student anticipates with apprehension, and in which he will have to compete viably.

With this in mind it is necessary shortly to consider the PSSC course and evaluate it from within this context as well as from the viewpoint of how well it motivates the student to learn. Before this kind of evaluation can be undertaken meaningfully, however, it is important first to determine just what our society does expect of its educators in the field of physics. From there we will have to consider what techniques the educator must employ if he is to successfully transfer society's required body of knowledge to the student as well as encourage the student's ability to proceed creatively from there. This will provide us with a broader background against which to evaluate the PSSC programme.

Educationally, what are the demands of our society? What then should be the aims of the teacher and his physics programme?

II

OUR OWN SOCIETY'S EXPECTATIONS OF PHYSICS EDUCATION

Through the ages, societies have invested in learning. Students have been the vehicle by which cultures have endeavoured to realize their aspirations of cultural advances, and economic and physical security. Through education and its inherent self-perpetuating ways the older generations ensure the step-by-step transfer of their culture to their young. As cultures evolve, so does the emphasis put on various aspects of a youth's education evolve: be it a drastic modification as in the case of a country invaded by a foreign group, or a more subtle one, as for example the technological race subsequent to Sputnik's launch. Any modification in a culture is marked by a similar change in demands made on its educational system, its aims and its content, and sometimes even the method used to achieve the goals.

Despite the continually changing educational scene, these alterations have not been so varied as one might suppose. With few exceptions there have been in history but two main thrusts to education: that which subscribes to the pursuit of knowledge for the sake of knowledge alone, and that which endorses the pursuit of only that knowledge which can be gainfully and usefully put to use. (Until the present century the use to which knowledge should be put was itself disputed: there were those who would set it to cultivating "virtue", or correspondingly, the spiritual, moral life, and there were those who wished it to inform purely for practical purposes. In this century, however, those most vociferously requiring of education that it intensify virtue have been quieted.) Often both views have been found in education simultaneously, with one or the other viewpoint enjoying some dominance over its opposite member. The two attitudes have seldom been comfortably compatible. Most often there have been bitter and vocal critics from each of the opposing sides.

Aristotle, in the 4th century B.C., commented that there was disagreement about what should be taught, whether it should be virtue, or the useful life, or simply "higher knowledge"--what we would rephrase "knowledge for its own sake". "No one knows on what principle we should proceed--should the useful in life, or should virtue, or should the higher knowledge be the aim of our training; all three opinions have been entertained. Again about the means there is no agreement...(Gillett,1969:26)." The Spartans chose unanimously to educate for the practical good of the community, and not for the individual's satisfaction. Europe in the Middle Ages educated also for an exterior purpose: not for the good of the community though, but for the good of the Church. The Renaissance directed the aims of education toward self-realization and self-development, characterized by Montaigne's "know thyself" (Gillett, 1969:103). A little while later, Bacon in 1600 discredited the validity of reasoning as a means for discovery, insisting on the necessity for observation of the real world to arrive at truth. With him came the push toward the "scientific method". At the same time he said: "Studies [education]... are perfected by experience... studies themselves do give forth directions too much at large, except they be bounded in by experience. Crafty men contemn studies, simple men admire them, and wise men use them...(The College Survey, 1951:321)." (The emphasis is mine.) His influence, then, was in the introduction and encouragement of the study of applied science. 18th century Germany recognized that there were to be two streams for its schools: one was practical and utilitarian for those who could not go on to university, and one was "academic", designed for those intellectually inclined. John Henry Newman in Victorian England pleaded eloquently for knowledge to be its own end, and for learning institutions to stress this bias. Even in his own time he had many vehement critics, including Matthew Arnold and the scientist Thomas Huxley, the former of whom argued education must serve the axiom "know thyself" (how kin to Montaigne) and the latter stressing the essential unity of knowledge and its practical application: "The diffusion of thorough scientific education is an absolutely essential condition of industrial progress... (The College Survey, 1951:1091)." Benjamin Franklin took his stand stating that America's students should learn things useful and ornamental, but always within the context of which professions the students would enter. Dewey in 1934 claimed:

> "The acquisition of skills is not an end in itself. They are things to be put to use....to make an individual more capable of self-support and of self-respecting independence....[and of] services rendered to others....The educational end and the ultimate test of the value of what is learned is its use and application in carrying on and improving the common life of all."
>
> (Gillett, 1969:201)

He attacked sharply the notion of knowledge for its own sake, accusing it of prejudice, elitism, and snobbery, saying, "There is no greater egoism than that of learning when it is treated simply as a mark of personal distinction to be held and cherished for its own sake (Gillett, 1969:201)." In the years spanning 1920-1935 education in the western world was directed largely at serving a useful purpose, though to which manner of purpose was remarkably evenly divided between those studies expected to develop the individual and his sensibilities and those meant to serve an entirely practical purpose. This is not the case today.

What is it we in Quebec expect of our students in the 1970's and 1980's? What are the aims of this culture, and indeed, of what does this culture consist?

One of the major documents governing and defining our present educational aims and content is the Parent Report[1], issued in 1966. This report emphasizes that our industrial society makes demands on education hitherto unknown, demands complicated by this society's insistence that education be accessible to all (The Parent Report, 1966:2-4). Unlike Sparta and later European countries where severe selection took place among those aspiring to higher education, the Quebec Government insists that everyone have the opportunity to be educated and develop his own personal attributes. Because it is recognized

---

[1] Monseigneur A. Parent, REPORT OF THE ROYAL COMMISSION OF INQUIRY INTO EDUCATION IN THE PROVINCE OF QUEBEC, Quebec: The Queen's Printer, 1966, Part Three A.

that in our society education must be a democratic process, this means that a wide variety of students must be considered when implementing education programmes. Education therefore has to be broad and versatile--extending, if necessary, beyond the normal years. In other words, there must be provision for purposeful and continuing education (The Parent Report, 1966:2-4). The citizen, to be a properly functioning member in this democratic society, must be educated if he is to be asked to exercise his democratic privileges intelligently, especially in a society involved in rapid social and technological change, which was where Quebec found itself in the 1960's. Some emphasis must therefore be put on the preparation of all individuals for the technological world in which we live. Our age demands this. Indeed, the trend of the past century has been toward this.

Judging by what happened at Beaconsfield High School, the programmes introduced there about 1969-1970 were to help in fulfilling the aspirations of the Parent Report. The enrollment in the science courses rose as did the probability for a job or career in technology. Industry was growing all around the West Island area, and the sons and daughters of the company owners and workers naturally accepted that they too would find themselves in that industrial environment. Indeed, the companies expected to draw the school's graduates into their labour force. It became common practice in Beaconsfield High to invite members of the industrial world into the school to talk to the students, to guide them and interest them in the various fields available to those appropriately trained.

Not only have the representatives of industry shown interest in this approach, but they also voice their opinions about education's product. It is evident from these opinions that industry feels the students are insufficiently prepared for their roles in industry.

One supposes that anyone entering an industry has to be trained for the job, regardless of the person's educational background. Consequently, given that industry is in a state of rapid flux, it is understandable that the complaints revolve around the fact that graduates simply are not much use when they first appear at the company, they are somehow not versatile enough, not capable of accomplishing practical tasks.

The need for practical experience in the science-technology field was underlined at one stage two years ago when representatives from industry were invited to come to the school to tell students about industry's view of the schooling process. Teachers and these representatives became bitterly polarized when the industrial representatives attacked bluntly and insistently the poor calibre of student hoping to make it in the work force. The teachers were blamed, the modular scheduling came under fire as too lax, the prevailing mood was, "Whatever happened to good old-fashioned learning and sweat?". Industry apparently was not happy with the schools' product. What they were really complaining about were two different things: one, that students were ill-prepared to cope practically in industry; and two, that students were lazy.

A vice-president from an electronics engineering firm said that graduates from Waterloo University were much more in demand in his field than students from McGill University. The difference, according to him, stems from the fact that Waterloo students go out regularly into industry for industrial experience, graduating not only with theoretical but with practical knowledge as well, and are thus ready to fit in as productive entities.

Industry's demands on education must be acknowledged as being significantly representative of our present society's demands. We live after all in an industrial society. What, then, of their two major complaints? To consider their second complaint first: laziness seems to be a malaise infecting all workers in general, though admittedly it would seem from all accounts that it is the younger generations of workers who suffer most from it. The "old-fashioned work ethic" upon which this continent was founded is fast disappearing. To what extent the school systems are responsible for this trend is difficult to assess. Some would argue that the school systems, rather than causing the trend, are merely reflecting it, the causes of which must be found elsewhere. Some indeed would argue that the malaise is not present at all in our schools. A realistic view, however, would admit that the malaise is real and is found in the schools as it is in every other sphere of life. While it is a sociological problem, it would benefit from some changes in our school systems. However, the schools acting alone would be incapable of completely eradicating such a widespread infection. Certainly, a particular approach to the teaching of high school physics is not going to directly affect this malaise one way or another.

A particular teaching approach in physics might well, however, directly affect a student's ability to cope practically in industry.

Whereas education must not be directed solely toward fitting in with industry's demands, we must not overlook the need, both from society's as well as the student's point of view, for preparing him for a life in a technological society. The problem in achieving this is that unfortunately the school and its teachers must by some magical process determine how to proportion the student's time so that he achieves maximum development personally while still being molded to take his place in the work force. The school, teachers, and students are placed in a very precarious and indefensible position. Our programmes must provide the meat, the practical, applicable facts, since our society expects students to have these, yet simultaneously we must inspire the students in their search for a deeper and more universal pattern and meaning to the work they are performing. This is and always has been the concern of the "society" of man and is therefore the concern of education. The school programmes thus owe it to the student to show him both theory and application. That this is a monumental task is no understatement. Not only has the body of knowledge available to the student grown tremendously in the past century, making selection of just what to choose to teach increasingly difficult, but the attendant rapid evolution in technology makes it next to impossible for the educator to keep abreast of technology's training requirements.

It is obvious that the industrial orientation programme discussed in the last chapter attempts at least partially to solve this dilemma. But educators themselves must share the responsibility for achieving these aims. Courses must wherever possible be aimed at fulfilling both criteria: providing the theory and making it relevant practically to everyday life as well.

The PSSC physics course has succeeded admirably in providing theory to the student. It has failed on too many occasions to indicate the application demanded by today's technological society. It is to fill this gap that I have modified some of the course. It has been my feeling that not only does the subject material lend itself naturally to being concretely useful in everyday life, but it behooves any responsible educator to ensure the emphasis of its relevance, both for the sake of the student's greater appreciation of the subject and for the sake of the society into which he is soon to be dislodged--charged with the responsibility of enhancing its culture.

Argued in more generalized terms than from this standpoint of the needs of our industrialized society, we reach the same conclusions: Our culture is experiencing a shift in mood from a sense of isolation in a vast uncompromising universe where all that happens is out of our control, to one of a sense of participation in a universe which is a home for man, a home which he must protect, explore, and hopefully understand. This is not to be misunderstood to mean that individuals feel less lonely than before or any greater kinship with each other than before, but rather it means we recognize we have a responsible role to play in our environment whether we like that fact or not. We affect our environment.

We must therefore equip ourselves to deal intelligently with our surroundings, with our real world, if that world is to be sustained in its natural state. To achieve this we must prepare our students to cope in the real world they are soon to enter. This involves a substantial emphasis being placed on the relevance of physics learning.

III

HOW STUDENTS LEARN

To plan a specific course of study one must appreciate first how the process of learning occurs; only then can an efficient system for learning be designed. Until recent years it was considered sufficient simply to present the subject material through either the written or the spoken word, as on a platter, to be eaten and digested by the student. The student's role was unconsciously (I say unconsciously because it is doubtful much thought was given to the student's role except that it was to learn) that of the passive receptacle which, upon being filled was then expected to give back what had been given whenever such demand was made. Those who complied exactly were labelled naturally bright; those who varied in any way were dull and stupid. Conformity rather than initiative and originality were the criterion by which students were judged. Much has been learned in the past 50 years about how one learns which has tried to change all this.

Jean Piaget has carried out educational research on children since 1927, theorizing on the nature of mental structures, and finally proposing that all children go through certain stages of intellectual development. Although he has been widely criticized for lack of precision as well as for using improper controls in data gathering (Ausubel, 1968: 191-193), his work on the recognition of stages of development has spurred much research and educational innovation.

Piaget draws a distinction between development and learning. He defines development as being the essential process of growing: the development of the body, its nervous system and its mental functions. It is spontaneous. Learning on the other hand, is provoked by situations--by a psychological experimenter, a teacher, or some other external situation. Each element of learning occurs as a function of the total development of the individual, which development (though not the learning) ends with the arrival of adulthood (Piaget, 1964: 176). Learning added to more learning does not create development, as some psychologists would have it, but rather learning can only occur once the individual already has within himself the structures of development, of "knowledge", which will enable him to receive the learning. Children therefore must do their own learning in their own time.

He says of knowledge: it is an operation. It is not merely a copy of reality.

> "To know is to modify, to transform the object, and to understand the process of this transformation, and as a consequence to understand the way the object is constructed. [This] operation is thus the essence of knowledge; it is an interiorized action which modifies the object of knowledge."
>
> (Piaget, 1964: 176)

By willfully interacting with the object, by recognizing in doing so the reversibility of those actions (that adding to can be balanced by taking away, joining can be balanced by separating, and so on,) knowledge is acquired, and logical mental structures are formed.

Intellectual development is marked by the building and rebuilding of these mental structures. Since no operations are carried out in a vacuum, since all are in some way related to other operations, then each is always a part of a total structure the recognition of which can only come about after many further operational activities. Many of these operations do not fit one's present mental structures, causing a state of disequilibrium. Old mental structures are disrupted and must be replaced. Through continued operational activity a new structure is developed and tested, either to be assimilated as a part of one's knowledge or to be rejected once again. This ongoing process, viewed by Piaget as a process of equilibration or self-regulation, is what constitutes development.

This intellectual development, according to Piaget, can occur only insofar as the particular operational level reached by the individual will allow. He lists four main stages of intellectual development, the precise ages for which he admits fluctuate as much as four years from society to society, and to a lesser degree from individual to individual, but the ordering of which remains universally constant (Piaget, 1964: 178). There is the sensory motor stage (from birth to about 18 months), the preoperational stage (from 18 months to about 7 years), the concrete operational stage (roughly ages 7-11), and the formal operational stage (starting at some point between the ages of 11 and 15). The first intellectual level, the sensory motor stage, is that level at which such practical knowledge as the fact that objects are permanent is assimilated; the second stage sees the development of the symbolic function--of language and of thought--but as yet the thought processes are rigid and incapable of reversal or true operational activity; in the third stage concrete operational activity begins--operations on objects, such as classification, ordering, spacial and temporal operations; but as yet there is no ability to verbally express hypotheses or to reason solely from the stance of hypotheses. This last stage arrives sometime in the teen years. According to other psychologists who have entered Piaget's field of study, the operational level, particularly the formal operational level, for even one individual can vary according to the subject matter being handled. For example, one individual might operate on a formal operational level in one subject but on a concrete operational level in another. Indeed, some claim that an individual often operates differently even within one subject area; for example, usually on a formal level in physics until one encounters some particular difficulty, at which time one reverts back to the concrete operational level (Ausubel, 1968: 193).

To what does Piaget attribute the development from one of these stages to the next? He cites four factors (Piaget, 1964: 178), all of which work in combination: maturation (which he uses to mean natural embryogenesis, including the physical growth of the nervous system and the brain), experience (one's own concrete operational activities and subsequent logical-mathematical perceptions), social transmission (linguistic or educational transmission; the interaction with others which shakes one from an egocentric view of things and exposes one to other views and thoughts often in conflict with one's own), and equilibration (the natural human tendency toward preservation of equilibrium, wherein if--as in the act of knowing--one is active and is consequently faced with an external disturbance, one will react in order to compensate, thus tending toward equilibrium once again. This equilibrium, defined by active compensation, leads to reversibility: a transformation in one direction is compensated by a transformation in the other direction. It is an active process of self-regulation, a "balancing out of knowledge" if you will, a fundamental factor in development.)

Piaget looks at the traditional thrust of education mentioned at the beginning of this chapter, that of "stimulus - response" activity, and finds it faulty. He maintains that if learning is a stimulus-response reaction, the stimulus can be a stimulus only if there is a structure already present in the learner to assimilate the stimulus. He suggests that the "response" therefore must be there first (Piaget, 1964: 182). Learning, he says, is possible only with this active assimilation, which in itself involves active operation by the student on the subject matter. It is the student's activity on the subject which Piaget finds is underplayed in the stimulus-response schema. The kind of learning situation Piaget proposes puts the emphasis on the idea of self-regulation, on assimilation.

All the emphasis is placed on the activity of the student himself. "Without this activity there is no possible didactic or pedagogy which significantly transforms the subject (Piaget, 1964: 185)."

In an attempt to translate his views on education into stimulus-response language, Piaget offers this recipe: first utilize the operations, then add the equilibration, and from there throw in the stimulus-response. That, for him, would constitute a sound educational method (Piaget, 1964: 185).

Where, then, does the Piagetian theory leave the science teacher, and what does it say precisely about the PSSC course as it is presently designed?

Certainly Piaget implies a certain "readiness stage" must be established before one can hope to "teach" effectively any given subject material. (You cannot teach higher math to a 5 year old.) He also doubts the various stages can be accelerated by external interference, maintaining that the progression from one stage to another is not the result of experience <u>or</u> social transmission but rather is achieved through internal equilibration, or a synthesis of the four factors mentioned earlier: maturation, experience, social transmission, and equilibration. Hence the teacher really must accept the present level of his student and build on that.

What <u>is</u> the level of development of the average science student? Most science courses of any weight are introduced in the high school years, supposedly at the time the formal operational level is reached by the student. This means, then, that the student should now be capable of reasoning with propositions only and has no need of objects. He can form hypotheses and test them. To do this, he must isolate and control variables and exclude irrelevant ones, surely a form of "abstract" thinking.

What is the level of development required by science courses? As Renner and Lawson (1973: 168) describe it in their study of Piagetian theory,

> "The maximum educational gain that comes from the study of science is derived from the isolation and investigation of a problem. Quite obviously this involves the formulation and stating of hypotheses and using a form of thinking which can be described as, if..., then,..., therefore. That is, of course, propositional logic. In other words, science teaching should promote formal thought."

Here we encounter a number of problems. On the surface it would seem that student and subject are well matched: both exist on the formal operational level. However, as was explained earlier, the ages at which individuals achieve this final stage vary considerably, and it is not at all unexpected that a student upon graduation from high school might not have developed yet to the formal level. Others who have might, however, be operating on the concrete operational level in the sciences, or perhaps are at the formal level one month and regress to the concrete level another. Most psychologists studying Piaget seem to agree that the changeover to the last stage is slow, with many fluctuations occurring between the two levels within the one individual (Ausubel, 1968: 193-195). Thus it is probable that despite the chronological ages of science students, they are neither the majority of them operating on a formal level, nor are they consistently operating at that level. The match is no longer such a good one.

As well, it must be remembered that Piaget distinguishes two kinds of experience which lead to different kinds of mental structures: the first, physical experience, which is physical interaction with the objects of the world and leads to the development of structures about objects; and the second, logical-mathematical experience, which results when the learner finally perceives that his actions with objects produce an order in themselves. (For example, when he discovers that 10 objects when counted left to right provide the same result as when counted right to left, he can now make the generalization that the sum of any set of objects is independent of their order.) Now the student has a mental structure that he can utilize; a logical-mathematical structure. This latter structure is a more complex structure than that produced by physical experience, but without the physical experience first, it cannot occur. Hence, in the early structure-building stages the opportunity for the learner to interact with concrete material is essential. If we accept literally Piaget's words

"...coordination of actions before the stage of operations needs to be supported by concrete material," (Renner and Lawson, 1973: 166) then we must say, as do Renner and Lawson,

> "...regardless of age, the student must have materials to perform actions with until he can begin to utilize logical-mathematical operations....It is experience with the materials of the discipline that produces the person who can understand abstract content and <u>not</u> studying abstract content which produces students who can interact with the materials and invent abstract generalizations."
>
> (1973: 166)

Therefore, regardless of a student's age, if the subject material, <u>or even a concrete operation</u>, is either so new or so "difficult" as to prevent him from forming a logical-mathematical structure about it to be utilized later, then the subject matter must be handled at a more fundamental physical experiencial level until such time as he can progress to logical-mathematical operations. What this means in the teaching of science is that, for one thing, science at the high school level cannot be handled primarily on the formal level; it must deal in the concrete. The laboratory situation is imperative. Secondly, it means that a particular <u>kind</u> of laboratory situation is essential. In situations where either the body of knowledge contained within a lab or the tools used to carry out the lab are themselves so abstract as to prevent effective assimilation by the student, even though he may ordinarily operate on the formal level or even though he has interacted with the operation of the lab which is a concrete activity: if that lab is to be assimilated at all, it then either must be redesigned itself or be prefaced by another lab on the same general theme whose body of knowledge can be operated on by the student as a physical experience or whose experimental tools can be understood as real, so that the activity can be perceived by the student at the concrete level. Until this happens, even what was a concrete operation--doing the lab itself--is perceived by the student as abstract. Only once this concrete level of understanding has been satisfied can the student hope to progress, to build new logical-mathematical structures with which to face the more abstract work to come.

It is not enough, therefore, simply to utilize the laboratory approach in the teaching of high school physics. Rather, the particular labs themselves, not just their method but each of their bodies of knowledge and their operational tools as well, must be capable of being operated on by the student in the appropriate manner: either formally--if the student has had prior concrete knowledge of the material or of something so recognizably like it that his formal thinking can easily identify the similarities and hence achieve assimilation, or concretely if the subject material does not satisfy these criteria.

Let us assume for the sake of argument that all the above conditions for intellectual development are met. Will this in itself guarantee that the student will learn? My answer is a qualified no. The above conditions do not make learning occur, they allow it to occur. What, then, will ensure the act of learning?

The term most commonly used for what further is needed to ensure learning is "motivation". Unless the student is motivated from within, we say, he will not learn. But Dewey provides some ideas which help us look at motivation within a Piagetian framework. He warns that though it was in his day accepted that instruction must proceed from the concrete to the abstract, it was too often forgotten that in the experience of the young learner:

> "...only that which has a human value and function is concrete. In his...study... physical things are presented to him as if they were independent and complete in themselves. But in the actual experience of the [student], these things have a meaning for him only as they enter into human life."
> (Gillett, 1969: 200)

The material then, must seem relevant to the human situation if the learner is to perceive it at the concrete level. Until a student is operating on a formal level, all prior learning is necessarily, according to Piaget, centered around the learner's own experience and physical operations; it therefore can be said to be egocentric. Only once the formal, propositional level has been reached can the learner shake free, however temporarily or occasionally, of this inhibition. It is understandable therefore that the student operating on the concrete level demands from his subject a sense of relevance or applicability to his own life before he can proceed to assimilate it.

The work of Dr. Hans Selye[1] supports this view. He proposes that the student learns when he can see himself in a situation. Everything eventually has to return to the self since man is egocentric (Selye, 1974: 61).

This returns us, then, to the matter of what criteria science lab situations must fulfill. If a lab succeeds as a high school lab on the formal operational level, it can be assumed, using Piagetian theory, that at some earlier stage the student successfully came to grips with its problems on the concrete level and, if Dewey and Selye are to be believed, perceived its subject to be relevant. When a high school lab is aimed at the concrete operational level of the student, it must at the same time, according to Dewey and Selye, be recognizeably relevant to the human condition. When the student perceives the material to be relevant to him and to his situation, because of the nature of his egocentricity it follows that he also cares. This quality of caring is the essence of motivation. It is what provides the student with that "energized will" to learn (see Introduction), without which effective learning cannot occur. Thus a relevant lab (one whose material and whose aims the student cares about) dealing on the concrete operational level, or a formal lab which has been prefaced adequately by relevant concrete operations, should result in student learning.

---

1 Dr. Selye is the noted medical researcher whose life-long work has been a study of the effects of stress on the human being. His description of stress could be compared to Piaget's "disequilibrium", though Selye's interpretation is on a broader scale.

Looked at from this angle, the question whether learning is assured by fulfilling the Piagetian theory must be answered in the affirmative. But only so if it is accepted that a) relevance to the human condition is a requisite of the concrete operational level and b) self-motivation, in the presence of those conditions required by Piagetian theory, will produce learning.

As an aside to the subject of motivation, when one states that a sense of relevance in subject material is required before one is motivated, this implies that one must have at least some generalized view of what the subject material is about, or what its application to the human condition is, <u>before</u> one begins to investigate and assimilate the learning material. This seemingly backwards order of events is not really backwards at all. It is, as we have seen, necessary psychologically. Furthermore, it does not imply that the total of the end results are fully understood prior to the assimilation process; it merely requires that a general human goal, about which one cares, however vaguely defined the goal may be, must be perceived from the beginning. This generalized goal will be quite different in kind from those particular results one accumulates by the end of the operation. Quite simply, it means one must have a fully satisfactory understanding of what the <u>question</u> is, and even <u>why</u> it is, before one can effectively search for answers.

How does the PSSC physics course fare within this context?

Briefly, although it certainly uses the lab situation as a teaching technique, it does not always concern itself carefully enough with the level of student to whom it is aimed and rather too frequently expects concrete operational thinkers to interact with the course on a formal operational level. In this it is not unlike some other newly developed curricula in science: "Clearly," said Kohlberg and Gilligan recently, "the new curricula assume formal operational thought rather than trying to develop it (Renner and Lawson, 1973: 169)." It fails as well to be relevant as often as it might, resulting predictably on these occasions in a lowering of student motivation, interest, and accomplishment.

Just where the PSSC course has failed specifically, and what I have done to amend the situation, are our next concerns.

IV

REASONS FOR MODIFYING THE PSSC COURSE

The PSSC course as it stands entertains educational aims and methods which are both viable and commendable. In the new Sputnik era of the late 1950's educators recognized the need for a new curriculum capable of teaching basic physics principles in such a way that the student would be able to progress smoothly from that course into more advanced physics. They hoped that by providing a curriculum with more "hands-on" experience for the student, such a smooth transition could be made possible. Out of this need the Physical Science Study Committee at the Massachusetts Institute of Technology developed what is referred to as the PSSC physics course. It is an inductive, experiment oriented introductory physics course aimed at developing students capable of progressing smoothly from its course into modern physics. Contrary to the traditional physics course which it parallels and in some schools replaces (the Regular Physics 512 course), it utilizes the concrete approach to learning favoured by Piaget, by involving the student actively in the lab situation. It is the student's activity in the lab which is his primary learning vehicle rather than his textbook learning.

Since, as always, implementation of programmes lag considerably behind their initial introduction, it was 1971 before Beaconsfield High School integrated the PSSC curriculum into its science programme. At that time I had been teaching the Regular Physics 512 course for a number of years in that school and was aware of some of its deficiencies. It was my feeling that a physics programme should offer more than a compendium of facts and figures, held together by the binding of the book. That is why when the opportunity arose in 1971 to inform myself about the PSSC curriculum with a view to introducing it into Beaconsfield High's courses of study, I was more than eager. I was convinced that an emphasis on the lab approach would make physics appear as a real form of personal inquiry to the students, leading them through their own efforts to initiate further inquiry. I sensed this could be but a healthy form of learning. With this end in mind I participated in a course at McGill University aimed at orienting the teacher toward teaching high school physics through lab activity. I looked forward to this new method of teaching physics as one that would present a strong unifying theme to the material, and which would make maximum use of the investigative experience-centered approach.

The PSSC text with its theory and the lab manual with its open-ended lab instructions both were formal, coherent tools given to the students to enable them to progress through certain topics in physics in a similar formal, coherent spirit. The school board provided special lab equipment to help me teach the course, and I found myself adapting naturally and enthusiastically to using it. There is, however, a fallacy in assuming that if one has the textbook and the equipment one also has the essential ingredients for a successful programme.

In my first year teaching the PSSC course I began to sense some of its shortcomings. At first I assumed they were in fact shortcomings in my own classroom presentation as teacher. Somehow it seemed that I was not implementing this laboratory approach properly. For one thing, the students were not appreciating all the material the way I had hoped they would. For another, students seemed to be experiencing real difficulty in understanding some of the work. In time, however, I realized that much of the fault lay with the PSSC course itself.

I discovered that when the students seemed not to appreciate the material as they should, they in fact were feeling a certain lack of applicability in what the PSSC course was asking them to do. Though all the labs were in fact concrete activity, some of those activities seemed to have no purpose in them that was real for the students. Although most of the students appeared to be willing to go through the motions of performing these labs, and were quite willing and even eager to co-operate with me as the teacher in an effort to carry out their activities, they seemed in these instances to lack that spark of enthusiasm I felt was necessary to real learning: the spark from within themselves. They were willing to accept my word for the value of these physics activities, but they obviously did not put a similar value on them themselves.

It was sometimes difficult for me to anticipate to which labs my students would not respond. I found that there were several occasions when I personally found certain labs fascinating, yet the general student response was apathetic. Whereas I was intrigued by the various ripple tank labs, for example, students lost interest in them very quickly. I saw the labs as the pedagogic vehicle whereby their concepts were tied to what was, for me, a real situation. The labs, I thought, provided a real basis for the appreciation of wave motion. It became clear, however, that the students did not see those labs as real life situations, but rather as contrivances; extensions of the textbook. Students all too often asked what the point of all these ripple tank labs was. They simply were not ready to appreciate what they were doing with the tanks.

While I wondered if the fact of my own greater appreciation of such labs was merely a natural outcome of my own particular interests and "bents", I wondered too if, in the event I could make the material relevant to my students, this would not increase their enthusiasm for the subject. Was it just a matter of personal preference? In discussions with some of my colleagues also involved in PSSC teaching I discovered that they too were finding certain labs falling short of their goals[1], either by being too abstract and "difficult" or by being irrelevant in the students' eyes. They chose, it

---

[1] All seemed to agree that the following labs in particular seemed weak teaching tools for their students: "Analysis of an Experiment", the "Millikan Experiment", "Refraction of Waves", and "Changes in Potential Energy".

seemed, largely to eliminate the offending labs, in some cases substituting something of their own--a book report, a demonstration, or a simpler lab. I was not sure I wanted to eliminate the labs in question. If I had felt that these labs were dispensable, which I did not, I probably would have followed the lead of my colleagues and either eliminated them or substituted something else. However the fact that I found each lab interesting made me curious about whether a similar degree of interest and involvement could be developed in the student. I felt that if it could, the students' learning processes would be improved.

At the same time that I was concerning myself with this question, I was having a close look at why certain PSSC material was not being absorbed and understood adequately by the students. What, if anything, did these "trouble spots" have in common?

I already knew that, as in the case of the ripple tank labs, the students found some labs irrelevant within their own life context. I knew too that students found some labs too hard. The "Millikan Experiment" lab was a good example. Prior to this lab students have had no formal exposure to buoyant force, they are not quite sure by what mechanism terminal velocity occurs because they are unsure of the roles of gravity and "weight", and they have no idea how the electric field causes a certain constant velocity in this situation.

Seen in this light, how one can calculate a charge/mass ratio from this variety of quantities must seem like magic to these beginners. And, in fact, comments on this lab are as follows: "It's a hard one on the eyes" and "Other than that it doesn't work, what else were we supposed to get from it?". Students are unwilling to see the lab merely as a technique and lab exercise because they instinctively are trying to re-live Millikan's adventurous discovery. After all, his work and its results involved excitement, so why can't their search be exciting too?

In both these situations, where the lab appeared either irrelevant or too difficult to be satisfying, it seemed that a higher level of knowledge was expected of the student than was realistic. Looked at in retrospect through Piaget's eyes, it is likely that I found the ripple tank labs absorbing because I was already well into the formal operational level in physics, having greater age, experience, education, and opportunity for the synthesis of these (equilibration) than did any of my students. The somewhat abstract activity of those labs, therefore, could be thoroughly satisfying to me. The students, however, were not being allowed the opportunity to be introduced to this material at their own level. They appeared to require a yet more basic, more real activity than ripple tanks in order for them to find the activity relevant. It was equally true that students seemed to require a more basic approach to the "Millikan Experiment" labs. As long as its activities were too complex to be properly understood, the work could not seem relevant to my students.

I was becoming ever more convinced that the question of relevance was basic to successful learning. Without it, I could not expect my students to exhibit that spark of enthusiasm I felt was necessary for them to learn effectively. I was also becoming more convinced that for the students to find relevance in their subject material it was necessary to aim the material very carefully at their true operational level.

When I found that certain subjects in the PSSC course were noticeably more successfully received by my grade 11 students than by my grade 10's, it was necessary for me to determine why. The likeliest reason seemed to be that the grade 11 students had by virtue of their extra year in age more maturity, experience, and knowledge with which to approach their subject than did their younger peers. However, the section of the course dealing with wave motion, which more than any other showed a marked contrast in suitability to age group, revealed what more immediately might be causing this variance in success. The text reading level of this section is very high. An analysis by the Fry Readability Graph Method (see Appendix A) shows that it is at the grade 12 reading level. Upon further investigation I found that many other sections of the text are in fact at the grade 12 and early college reading level. The lowest level found anywhere in the book is grade 11. Although the Fry method of determining the readability of a text is not given much credence by some reading specialists, my students obviously were having a great amount of trouble reading the book: the grade 10's particularly in the wave motion section and the grade 11's in the section on electricity and magnetism.[1] The writing style is particularly difficult in these portions, and the presentation is aimed at a level of understanding above that on which my students appeared to be positioned. It is not surprising, then, that my grade 10 students were consistently achieving below the grade 11 students in the more difficult sections.[2]

Because of the problems my students were experiencing in these and in other areas I decided I had to modify the PSSC material in such a way, hopefully, as to ensure a more effective learning experience for them. I was anxious to see if, by designing material my students could find relevant, they would not only understand their work better but they would be more enthusiastic and more motivated as well. To this end and for as many of the "trouble spot" areas as time would permit, I decided to shift the classroom emphasis slightly from the "purely scientific" to demonstrating society's need for the practical aspects of new-found know-

---

1 The grade 10 students do not reach this section of the course until the last half of their grade 11 year.

2 For a more complete discussion of the reading level of the PSSC text and the ramifications of that level as expressed in government directives, see Appendix K.

ledge. Prior to doing certain of the "problem" experiments I wanted the students to spend some time with an activity that developed a feeling, a paradigm, for that subject already. It was not so much my intention to change the PSSC course, or subtract from it as I had found others were doing, but rather I was determined to add to it. What I added had to be real to the students in their everyday lives.

Much of what I did in the beginning was "spur of the moment" in nature, usually because I felt that the slant I took should be timely and immediate to the personal lives of the students. Though this was less structured an approach than I realized ultimately would have to be the case, it was noteworthy from the start that the students responded to this kind of evidence of the "immediate reality" of physics. I found this a hopeful, positive beginning.

At about this time when I was beginning to develop my additions to the PSSC programme, a Masters of Education programme on the Teaching of High School Physics was introduced at McGill University. This seemed to me to be opportunely timed. I enrolled, hoping to learn from it anything which might help in my attempts to revise the PSSC course. It was of interest to me to discover that so many of the ideas I had concerning the PSSC course were specifically discussed, though not within the PSSC context, by other educators and psychologists.

Piaget, for example, shed much light on the phenomenon I had encountered with experiments such as the ripple tank labs discussed earlier. It is remembered that in these experiments, although the students were indeed working in a lab situation (which when I first began teaching the PSSC curriculum I had assumed would be almost by definition a good learning medium,) they were unable to relate to these labs in any way. I had decided after some time and consideration that this must have been because the tools the students were using seemed artificial to them; they could not muster any real interest in them. Piaget's theories suggested to me that this was because the students had not had sufficient prior concrete activity to establish concrete structures (to use his language) about the models used to explore the subject. Because the students failed to see any relevance in the tools of these labs, the labs were in fact taking on the role of teaching through the old "stimulus-response" method. The concrete operations and subsequent equilibration which Piaget had insisted must precede the stimulus-response motif,[1] were missing. This seemed to explain rather well why my students' response to these labs was of the parrot variety: the stimulus offered by the labs, without the prior concrete experience they needed to have had, could not produce real knowledge; neither could it produce any sense of personal motivation[2]. Without either of these factors present it also followed that the labs could not

---

[1] See pp. 27-28

[2] For a discussion of what constitutes motivation see pp. 33-34.

lead to original thinking.

Although there appeared to be a dearth of scholars dealing with this question of the quality of not only lab content but of its materials as well[1] I did find one author, Gerald R. Holton, who in "What is Conveyed by Demonstrations" (1970:72) referred to this problem. In discussing the introduction of the concepts of interference he argued that one should not use the model of a ripple tank, or blackboard diagrams and explanations, but rather one should first explore the phenomenon with an industrial or research device, the "real thing". Since this real device was more fundamental to the student's experience than the lab model it should give better assurance of student learning. He did not advocate, however, eliminating the ripple tank; just delaying it until this preliminary step had been taken. He felt the ripple tank should come in later for more hands-on experience.

This thinking seemed strongly to align with my own. It seemed to me that for these occasions, pre-lab activity of a very basic type was required. The activity had to afford the student the opportunity to interact with material he would find real, or relevant, to his own experience. His models had to be real, or relevant. From this experience he would, hopefully, be able to go on to interact successfully with the new

---

[1] Many were discussing the quality of lab content, but the issue of the quality of lab models was not a lively one.

learning as found in the prescribed PSSC labs.

It must be stressed that I did not find such preliminary groundwork to be necessary for all of the PSSC labs. Many of them were obviously well suited to the level of my students. In those cases, however, where I found the students were consistently encountering difficulties, I felt extra-labs would be helpful.

Relevance was essential to my modifications, both in topic and in models used. Relevance was required to help the students understand. Just as important though, I had observed that without this sense of relevance, my students tended to lack that quality of caring so essential to the learning process.

It was with these aims of improving student understanding and motivation that I began providing additions to the PSSC programme.

V

ADDITIONS TO THE PSSC EXPERIMENTS

The PSSC laboratory manual contains 47 experiments. The Teacher's Guide suggests about 20 are of primary importance, and the others are auxiliary experiments to be used if and when time permits. I have found that I can schedule about 21 labs in the course of a year, averaging about one experiment a week. Of these 21, I have found it advisable so far to add material to 5 experiments, sometimes adding more than one extra activity for an experiment. Although I intend to add more material to certain other experiments in the future[1], I shall restrict my comments in this chapter to the work I actually have done so far.

My additions to the experiments are designed to provide concrete operational experiences where the PSSC course has provided formal operational material incapable of being effectively assimilated by my students. As I mentioned in the last chapter, the additions are not meant to supplant the regular demonstrations which normally are given students in the course of a presentation in class. Rather, these extra experiments exist either to motivate the students to investigate further a phenomenon or concept contained within the standard lab or they exist to clarify the students' understanding of the PSSC lab when they eventually perform it. As it stands, the PSSC lab manual makes no attempt at placing its curriculum within the larger life context. As described

---

[1] For example, "Young's Experiment", "The Force Between Two Charged Spheres", and "Randomness in Radioactive Decay", all of which I feel would be more effective with the addition of preliminary material.

in chapter 3, if students are to learn, they require a setting or a framework within which to place new information. The PSSC curriculum appears to assume the students already have this framework; it has been my experience they do not. Rather than leaving my students at my mercy, having to accept my esoteric view of how their work all fits into some important life sequence, I have chosen to try to provide them with the kind of material which will allow them to construct their own framework within which to place new information.

Experiment No. 1, "Analysis of an Experiment"

When a student opens his PSSC lab manual to Experiment No. 1, he is faced with "Analysis of an Experiment" (see Appendix B), a lab which asks students to mathematically synthesize information, a process far above the operational level of the student just beginning grade 10, and likely above the level of most students starting grade 11. Specifically, it asks the student "to present and analyse these results in a form which will enable you to predict the outcome of similar experiments". Admirable as the lab's intent may be, it has been the experience of myself and of every PSSC teacher with whom I have conferred, that students are incapable of fulfilling the lab's request. They neither have experienced fluid dynamics as an overtly recognized physical phenomenon nor have they experienced it on a theoretical level; neither have they the computational skills with which to satisfy the lab.

This lab is not a lab, therefore, which draws on a student's present knowledge or understanding, but instead it calls on the student to exercise what are minimal computational skills and problem solving abilities: "minimal" because he is still but half-way through his high school years and yet has much to learn in mathematics, and because, after a summer of supposed mathematical inactivity, what skills he does have are more than a little rusty. From this rather shaky ground the student then is asked to further abstract the information by evaluating his findings by graphical analysis.

Since this Experiment No. 1 is a "dry lab" where the relationships of flow rate out of a container is given as a function of height and opening diameter, how can the student be asked to generalize on the data when he is not necessarily convinced that there should be a relationship?

Whereas the stated aims of the lab are worthwhile goals, as a teacher I must confess that those stated aims are to be hoped for by the <u>end</u> of the school year rather than at the outset. It is the object of the course to <u>develop</u> the required abilities, not to assume them at the outset. The method chosen, and the sequence of the labs is unfortunate, because students react negatively toward the labs from then on. "PSSC labs are impossibly difficult" is a typical reaction heard from students attempting this lab as their introduction to the whole course. They have been initially exposed to PSSC Physics on a decidedly negative note. Any attempt to change this view is an uphill battle the rest of the year. What possible enticement toward further study can be offered the student, having been confronted at the outset with such an impossibly formidable task?

It would seem obvious that such a lab exercise as this experiment No. 1 never should be thrust upon a student without some prior background preparation. One asks what <u>is</u> done generally by teachers to prepare their students for this particular lab, and what <u>can</u> be done in the spirit of an experiment oriented programme? On attempting to discover the answers to these questions I found that, as described in Chapter 4, rather than trying to prepare their students in such a way that they could deal profitably with this lab, teachers generally have been omitting this lab altogether, or sometimes substituting it with a "lesson", rather than an experiment. This is unfortunate, since it has been my experience that this need not be an impossible lab, that indeed valuable lessons can be learned from it by the student <u>if</u> this lab is prefaced by suitable material.

<u>A Pre-Lab to Experiment No. 1, "Analysis of an Experiment"</u>

The following has been specifically developed to overcome the present PSSC shortcomings by introducing students in a more natural and satisfying manner to their PSSC programme:

natural in that it allows for the sequence of learning as outlined in chapter 3, and satisfying in that it allows the student a sense of self-motivation leading to genuine discovery on his part. It also attempts to draw the student into an acceptance of the experimental approach as consequential. Whereas any medium may have been chosen, I chose to use water and a set-up not unlike that with which experiment no. 1 deals, in the hope that students would transfer the experience and see the significance of experiment no. 1 once they moved on to deal with it.

My first class in physics consists of a discussion of the meaning and measurement of various quantities; temperature, weight, time, reaction time and the like, illustrated with equipment. At this session I try to impress on the students not only the power of observation, but also the shortcomings of various means of measurement. For homework the students are given the following instructions:

> "Fill the kitchen sink and measure the time it takes to empty. Try this several times. Fill the sink half as full and measure the time it takes to empty. Fill the sink, put the grid from an ice cube tray over the outlet and measure the time it takes to empty. Try swirling the water in either direction to see if the sense of

> rotation makes any difference in the time it takes to empty. Keep some kind of record."

The instructions are verbal, and not written on the board. There is no need. The students can all visualize the scene in the kitchen or bathtub where the experiment is going to be carried out. There is no abstract action, only curiosity. What is this physics thing all about anyway? Why the ice cube tray? As they shuffle out of the classroom there is animated chatter and the extremists in the group are already discussing how they will swirl the water fast enough so that none will go down the drain. Students are feeling confident, and physics is gaining acceptance.

The next class usually starts noisily because people have data which they can compare, speculate over, and argue about. "How come your time to empty is so low?" "What did you use instead of the ice cube tray?" "A wire screen is no good." As far as I am concerned there is absolutely no doubt that the PSSC course is now in progress. There is no formality. No one has the "wrong" results. Every experiment, although supposedly they all measured the same thing, has turned out differently.

Quite naturally students compare each other's data and attempt to isolate the causes for their times being different.

We draw sketches of the vortex in the hole and the students suggest that when there is air going down the drain, there is no water going down. The role of the ice cube grid is obvious to the students when they look at the emptying times with and without the grid.

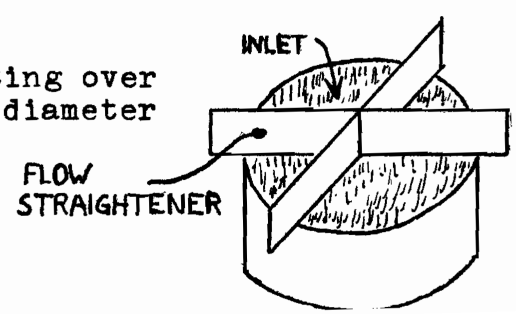
Because they are intrigued by the effect of a flow straightener[1] an excellent opportunity is presented to develop further their grasp of fluid dynamics. This development appears unplanned to the students, but the stage for it has been quite deliberately set. It is in fact an effective way to get the students to accept the idea of getting their hands involved in "doing" physics.

Over a 3 or 4 lesson period I introduce a series of activities which give the students experience in performing physics experiments while at the same time developing their awareness of fluid dynamics.

Using cans with holes in the bottom center (equipment borrowed from other physics courses intended to investigate the length of sound waves in air) students are asked to fill the cans and then allow the water to run out, paying specific attention to the vorteces as the water swirls out

---

[1] Vanes or baffles projecting over inlets or outlets, across the diameter of the opening.



of the can. They are asked to do it again; this time adding a drop of dye to the vortex. Because they see the drop of dye change its shape I raise the question of what must be happening to cause the shape to change. Since they all can see that in fact the inside of the vortex is turning faster than the outside, causing the dye to change its shape, the question arises as to why. The next step is to show them a rubber sheet spread over a 70 x 70 cm frame. Under the sheet's center I have attached a pin by which the rubber is pulled down. This arrangement results in approximately a $1/r^2$ surface. This surface now allows students to inject marbles into orbit and students see that the inner orbits have a lower period. They thus can see that the vortex's shape, analogous to the rubber sheet's surface, is such as to cause this difference in period.

Students in this experimental demonstration are now ready to answer some sophisticated questions. Asked what would happen to the motion of the ball if it were slowed by friction, they readily answer that the ball would go quickly to the center of the depression. Can they see now the role of the ice cube grid?

"Why yes!"

"What do you think would happen if we were to speed up the swirling motion?"

"Of course nothing would go down the drain."

"Does the direction of rotation matter?"

"No."

"What do you think will happen to the amount of air delivered by a fan if vanes are used on each side of the fan to prevent any swirling motion?"

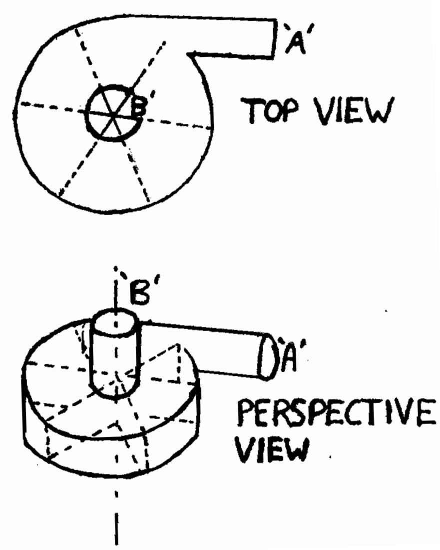
"More air will be delivered."

"From what you now know, list your criteria for the design of a container from which liquid will flow at the fastest possible rate."

"Well, vanes to prevent swirling. A big opening."

At this point I am always intrigued by the fact that students do not mention a tall container. They have been looking for all other factors affecting the outflow rate and they have overlooked the very one factor that Experiment No. 1 takes for granted as being known. At this point I ask one leading question, "Will water flow out more quickly if the hole is at the top or bottom of a container?" Most immediately admit that height is a controlling factor as well.

Next I develop the application of this swirling action found near outlets. The procedure is roughly as follows:



"Imagine a machine as indicated in the diagram. The machine has a wheel with blades inside a closed container, and the wheel is driven by a motor. If 'A' and 'B' are openings, will 'A' be an intake or an exhaust? Will 'B' be an intake or an exhaust? Why? What function could this machine serve?"

At this point some students will recognize the machine as being some sort of pump. The class is reminded of a hair drier (if a student fails to think of it, I mention it myself) and suddenly a look of recognition spreads over the faces in the class.

Since there was no problem identifying intakes and exhausts in the previous case, I ask what the intake would be if the wheel instead of being powered were to produce power.

"What will happen to the fluid entering the port of your choice? In what circumstances does one find a machine functioning in this manner?"

Most students find this last question difficult so I lead the discussion toward generating turbines. The homework assignment for that day is to look up and find out something about the different types of turbines and their application.

For the next class I have the current surface weather map taped to the blackboard, having obtained it from the

Montreal weather office.

Students are told that the highs and lows marked on the map are pressures, and are represented on our rubber sheet[1] which we used in an earlier lesson and are using once again, as high and low heights, just as the names suggest. The lines on the map are described as being contour lines, something with which many are familiar from their work in geography.

"If we release a ball on the rubber sheet, which way will it roll?"

"Downhill."

"If for some reason the ball is given a sideways push as it is being released, where will it go?"

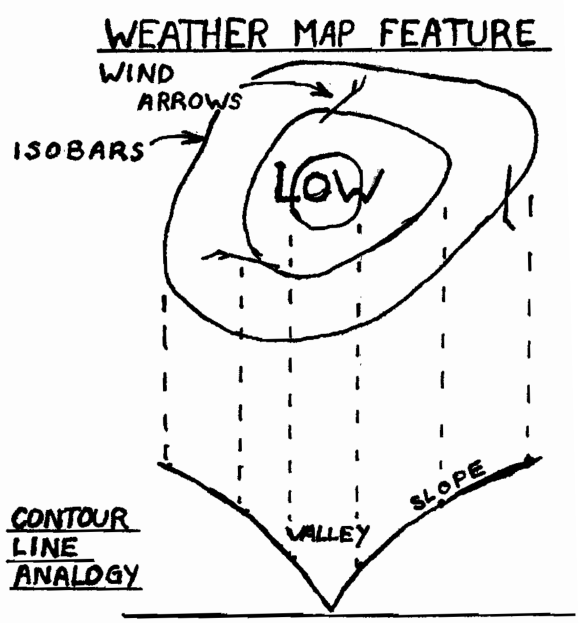
"Into an orbit."

"Come and have a look at the map and look at the alignment of the arrows which represent the wind direction. What do you notice?"

"They follow the lines."

"Exactly?"

"No, slightly inward."



[1] See p.56

Conversations with my students in 10 different classes have followed this pattern without variation as we work with the rubber sheet and the weather map. The development from this stage however, varies considerably, depending on questions students raise. Sometimes the discussion centres on the eyes of hurricanes, on fluid flow in pipes, or on air flow around objects as indicated by snow drifts or sand dunes.

Whatever direction the work takes at this point is irrelevant to me because from here on the students are involved in investigation out of their own curiosity, not because of direction from the teacher or the text. Because the student is beginning to be convinced that what he is doing is of some practical value to him, he is also gaining the impression that whatever hardships he will encounter, they will benefit him. His mental attitude towards his new physics course is encouragingly positive. It is true that at this point the student has been brought no closer to having the mathematical and manipulative skills required to cope with Experiment No. 1 (although he has been equipped with some foundational physics knowledge necessary to a comprehension of what Experiment No. 1 is all about) but it is also true that having done this pre-lab work he is less likely to become disenchanted with the programme upon which he is embarking even when that programme proves incredibly exhaustive, as will Experiment No. 1. At this point the students have been through four or five physics classes and there has been no work all of the students have not been capable of doing, yet almost all of it has been lab work or some other sort of physics related activity. Students have had to take readings, draw sketches, discuss with fellow students and teacher, and have had to look at the world around them. And in their minds, physics is related to that real world.

Ultimately the students tackle Experiment No. 1 in the manual, having had the concrete experience of my pre-lab activities. When they do, students will understand on their own that, quite contrary to what the manual says about the rate of outflow, the flow rate is not a function of diameter alone, but rather the specific design of the outlet is also a factor. When they spot this it is obvious that such recognition gives them pleasure. The eventual graphing and analysis of the data then amounts to an expression and representation of what they now already "know". Whereas without the prior experimentation both the data and its analysis would have been abstract to them, a mere assumption based on the authority of the textbook, now they need concern themselves with the analysis only, as the title to Experiment No. 1 suggests. Although the analysis itself remains vitally complex for them and requires much direction from the teacher, their hearts are in the work at hand and they are eager to carry on. Students thus have come away from the total experience having learned some experimental technique in the pre-lab, having learned that not everyone will get the same results, having learned to analyse data with the help of the teacher (help only in the data's analysis, not in the understanding of the experiment), and having had the added benefit of understanding how centrifugal pumps, turbines, and air masses work and move. The impression left with the students is that there has been a point to it all; and the class tone, one of serious excitement, reflects involvement. This contrasts sharply to the first time I had students do Experiment No. 1 without any sort of lead-in. At that time it was obvious by the long faces and defeatist attitudes that the experiment had succeeded in reinforcing their beliefs that physics is impossible; some were even prompted to request a course change.

It would appear from the fact that other teachers have abandoned this lab altogether that my initial experience with this particular experiment is a universally shared one. As the foregoing has shown, it need not be.

Extra-Labs in Wave Motion

Students find the lab work on wave motion generally tedious. Teachers and physicists recognize the need for students to be introduced into the wave-particle duality of matter; in fact, the PSSC course was specifically aimed at this. A problem arises, however, when students not only find the subject matter intensely difficult but they fail too to see any direction to their learning. Why are they learning all this? To where does it all lead? Quantum mechanics is a field too complex for the beginner to digest, yet somehow he must be exposed to it without sacrificing the positive relationships between student and subject matter so carefully built up in the early sessions of the course. The fact that this portion of the course comprises for grade 10 students close to half the year's work and for grade 11 students a quarter of their year's work makes it impossible to gloss over the section hurriedly in the hope that the next topics will prove more palatable or exciting to the class. The labs must be faced, but in such a manner as to hold the student's interest. The PSSC course, as it stands, fails to do this.

Most negative comments concerning lab work on course evaluation questionnaires I have given out, pertain to lab work on wave motion.[1] Students remain unconvinced that such an in-depth study is required in order to understand the optical phenomena they are observing. They are, in fact, unable to see the forest (physics) for all the trees (labs). They object to such detailed study since they see no ultimate goal. Telling them that the wonders of quantum physics will unfold before them if they will only pursue these labs is poor motivation and very authoritarian, the very thing the PSSC course is trying to avoid in its open-ended approach. Unfortunately too, the nature of modern physics is such that

---

1 See p. 92

The students are issued with 1:250,000 maps of the area north of Montreal, bordering the Canadian Shield. Rivers here are fast flowing as they leave the hills and slow when entering the lowland. Students acknowledge the difference in stream velocities, understanding somehow intuitively the role of gradient. Through my direction they discover that the fast moving mountain river meander wavelengths are longer than the river meander wavelengths in the lowlands. That, they say, is comparable to what happened when they tied a slinky to a string. In that situation the wavelength in the string holding the slinky was long because the pulse travelled quickly. On the other hand the slinky had a slow pulse speed and a shorter wavelength. The students are intrigued to discover the lowland is a slow medium with short wavelengths.

From a contour map it is not difficult for the students to derive the slope of the land in which the river flows, and they make an attempt at graphing the relationship between river meander length and the slope of the land (stream velocity). The idea of measuring the more easily derived meander wavelength to find the land's slope rather than taking the contour interval and distance to arrive at a gradient has strong appeal. Obviously wave motion as a concept is useful, and not merely an idea in a physics book.

To complete that lab exercise in the geography lab we--

the "geographers" and I--investigate why it is that the Bay of Fundy has such high tides. None of them has dreamed that the length of the bay along with the "wavelength" of the tidal action combined to give record tides. Again, the enthusiasm of the students can be felt as they discover the relationship of physics with yet another facet of their lives.

After the initial shock of taking physics out of the classroom students show some pride in knowing and studying this section on wave motion. Their renewed interest is obvious. Wave motion is not abstract or confined to the physics lab as it first appeared to be in the PSSC curriculum. Again, it has been a matter of demonstrating to the students that the study of physics is the study of the real world around them, a world in which they personally play a part, a world whose physical realities face them every day.

A Pre-Lab to Experiment No. 10, "Periodic Waves"

Since the initial success of this attempt at interesting students in the nature of wave motion, I have been using further out-of-lab excursions to observe wave motion in real life. On one such outing just prior to Experiment No. 10, I take classes outdoors to have them observe the wave features of clouds. Certain clouds--cumulus, altocumulus and cirrocumulus--often exhibit a periodic pattern in their arrangement. Once pointed out to the students, the pattern is obvious.

I use this occasion to call on their ingenuity by asking them to determine the wavelength of the waves of clouds. Students balk at that: "You mean those clouds way up there?" Discussion ensues as to what numbers are required so that the wavelength may be calculated. Eventually they decide that the whole thing can be solved by geometry, if only they could get the height of the clouds. At this point I give them the telephone number of the Montreal weather office, and one of their number scurries off to obtain the cloud height.

Judging by the general air of anticipation, it is obvious that once again the confrontation with the real world rather than the world of the lab has heightened their desire to learn. This is not just another example in calculation alone, but it is another example of wave motion in our surroundings. And what do the students learn besides the relevance of the exercise? Besides discovering the answer to the question posed, the whole exercise makes obvious to them the effect of parallax in determining the distance between clouds. It also demonstrates the validity of different methods of solution: some use trigonometry while others use scale diagrams.

If it is the purpose of physics to observe, measure and predict events in nature the students were certainly doing physics. Moreover they were enjoying the physics as well as the setting.

The follow-up to this cloudwave experiment consists of a half hour look at a current upper air chart which I have obtained from the weather office. Here I explain the long wave structure of the upper air flow, and, using the analogy of crests and troughs advancing from west to east, I tie this in with our repetitive weather patterns.

The discussions do not specifically add material to the PSSC labs on waves in water, since they are concerned with a medium other than water, but the students do see how their studies are applicable in explaining events which they meet in their daily lives. Hence that very important ingredient is present: student interest. The cloud observation exercise as well serves to provide the student with a firm understanding of wavelength, so that when Experiment No. 10 is begun the only really new basic notions facing the student are the ideas of frequency and its measurement. This allows Experiment No. 10 to serve as reinforcement to the understanding the student already has regarding periodic waves. The student can now concentrate on the mechanics of the ripple tank experiment rather than also having to attempt the understanding of the physics itself.

A Post-Lab to Experiment No. 11, "Refraction of Waves"

I have devised a third exercise to be introduced shortly after the students have completed Experiment No. 11, "Refraction of Waves". This involves taking the students to a non-destructive testing facility on the site at Montreal International Airport. Prior to going I pose a problem to the students: how can one check the interior of a piece of metal? How can one find flaws in a solid piece of metal? Other than suggesting the use of x-rays, it has been my experience that the students are not able to suggest a method to detect internal imperfections. To me as a teacher, having just had the students do a lab and textbook exercises on refraction and, earlier on in their course (Experiment No. 2), reflection, this is significant. Evidently the students do not and cannot transfer their new "knowledge" of the properties of waves to a new situation. And neither the labs subsequent to Experiment No. 11 nor the textbook develops the topic any further toward a practical end than was done in Experiment No. 11. The subject simply drops from the students' view. Where does this leave the student? How long will he retain the information to which he has just been exposed if he does not see an application other than the ripple tank and thin films of oil?

Piaget (1964: 184) uses three measurements to gauge whether or not real learning has occurred, the first two of which are, "Is this learning lasting? What remains two weeks or a month later?" and, "How much generalization is possible?". He wants to know if this is an isolated piece in the midst of a learner's mental life, or is it really a dynamic structure which can lead to generalizations. Obviously by these measurements my students have not "learned" from the refraction and reflection lab and their exercises. Students have not formed a logical-mathematical structure from their work to enable them to utilize it when I pose the above question to them. It is for this reason I take them to the non-destructive testing facility.

The aim is, then, to provide an extra-lab experience in the hope that, here, the information gleaned from Experiment No. 11 and the earlier Experiment No. 2 will find concrete application, and thus undergo equilibration, as Piaget would put it, resulting in their ability to generalize. Specifically, they become involved in an everyday problem where wave refraction and reflection are involved: the testing for cracks in airplane wheels.

Once inside the testing shop the students witness the use of ultrasonic waves for the detection of cracks. The testing apparatus consists of a transducer and a cathode ray tube read-out. The technician simply watches for anomalies in the reflected waves, anomalies which would be set up by inconsistencies within the metal. The technician shows the students what a normal, unflawed piece of material looks like on the screen, and then switches to the read-out of an identical piece; identical but for a crack in it. Students are amazed at the extent of the difference in wave-forms on the screen.

From having performed their slinky and ripple tank experiments, Nos. 7 and 11, they understand the phenomenon of reflection of waves from interfaces. We reinforce the idea that however small the crack may be, it is an interface; and waves will reflect off both sides of the crack, one reflection being delayed more than the other; a time difference revealed to them by pulse peaks appearing unevenly spaced on the cathode ray tube they are watching. The students are visibly impressed by how quickly and with such certainty the technician can check a large surface internally. Comments of surprise abound: "Wow", "Ever simple", "Is that all there is to it?". They ask questions pertaining to frequency of waves, and possible limits to the thicknesses and types of materials which can be tested.

Since the apparatus used in testing has appeared quite simple, the students' enthusiasm has not been whetted by the maze of gadgetry, but rather it appears that they are impressed by the simplicity and cleanness of the entire process. The visit has taken just a half hour, but it has made its impact.

As always, there is the hope that as a result of this exposure to a common, everyday application of wave phenomena, and as a result of their interaction with its application, the students will retain what they have learned and be able to build on it in the future. Particularly for the majority of the students, who will never pursue physics at the university level, it is important that they be given the exposure to extra-lab experiences dealing with wave motion such as the three I have described, since it is my experience that it is in these extra-labs rather than the PSSC labs that the biggest strides towards internalizing the subject of wave motion are made. Students going on in the study of physics in university will have at least a second chance to come to grips with the topic, but for the others, this is their only opportunity to build a basis of understanding.

A Pre-Lab to Experiment No. 32, "Energy"

The PSSC manual and its compilation of labs is particularly unimaginative in the energy and energy conservation section, relying on the theory textbook to deal with practical problems. The text does a thorough job insofar as it goes; however it consistently uses in its examples the laboratory gadgets "carts" and "kilogram masses", always just hypothetical objects rather than real situations. I often wonder what a kilogram mass looks like in a student's mind. The problems in the text are a challenge but not intriguing, and the one and only lab provided in the manual, Experiment No. 32--"Changes in Potential Energy"--is dull. Since the concept of the conservation of energy is important in physics, it is very surprising that the lab manual has only the one lab on the topic. Teachers with whom I have discussed this say that Experiment No. 32 is difficult for the students to analyse, and generally is disliked by the students because it does not fit obviously into work they have been doing.

Experiment No. 32 attempts to have the student correlate the spring and gravitational potential energies of a suspended weight. The student is to calculate the gains in spring potential energy and the loss of gravitational potential energy as the weight stretches a spring. (See Appendix B.) This should be an adequately difficult and complete experiment as a <u>first</u> lab on conservation. However, the authors insist on the student also introducing kinetic energy of the oscillating weight into his consideration of energy conservation. The way the instructions are given to the students invariably results in their focusing their attention on the tops and bottoms of the oscillations, missing completely the fact that the weight has a high kinetic energy going past the mid-point position of the oscillations. If this experiment were instead an ordinary string pendulum, the kinetic energy maximum would not be missed so easily. One asks if the same conservation principles could not be taught using a pendulum, omitting potential energy stored in springs, but using instead gravitational potential energy and kinetic energy as the variables. Furthermore, there has yet to be a student in any of my classes who has been able to determine on his own why the weight should rise as high above the neutral position, as it was pulled down below the rest position. It is an interesting question, but very abstract for a fifteen year old. Could the same question not be asked with better results if a pendulum were used for the experiment? Experiment No. 32 always strikes me as the "Dark" lab, because the students do it and then disappear somewhere into the dark, only to reappear a few days later with distraught looks, asking how to go about analysing the results. Even when they are told where to choose the reference levels, they have difficulty sorting out the data. All indications are that it is far too abstract, that it is not a lab for high schools, at least not unless it is most carefully prefaced with other material designed to lead the students more gently into its arena.

In an attempt to fulfill this aim I have developed a lab which in my estimation also fulfills completely Piaget's requirements of a concrete operational activity. It is designed to precede Experiment No. 32 and is simpler for the student from the standpoint that only two energies are involved compared to the three in the PSSC experiment. Before describing the lab, I would like to make it clear that students who have had the benefit of working on the pre-lab have submitted write-ups for Experiment No. 32 of a distinctly higher calibre than have those who have not experienced my pre-lab. The pre-lab students obviously have in the end a better understanding of what and why energies are conserved. What is more, students have found the pre-lab fun to do; it inevitably turns into a contest; and it appears already to have inspired two boys toward a career.[1]

The pre-lab involves the development of a paper model airplane lab, using paper model airplanes made of $8\frac{1}{2}$" x 11" sheets of paper. Students are given instructions to build their own paper models, using no more than one sheet of paper, with a view to having the students construct their own materials with which they are going to investigate changes in potential energies. To give the whole affair more credence to the "sophisticated" high school students I show them that "Scientific American" has held a paper model airplane contest, and I show them a book depicting the winning designs. At the same time I show them how to calculate potential energy, glide ratio, power, and efficiency. They will require these skills after the airplane lab when, for homework, they must analyse their data. The whole lab develops into a bona fide flight contest and students are given two to three days to prepare an entry.

On the day of the contest there is an official weigh-in, where models are weighed to $\pm$ 0.01 g. Two categories have been established: one for distance of flight and one for duration of flight; each entry is allowed two tries in each category. One of the students acts as the "standard launcher" to ensure that all planes are launched as equally as possible.

---

[1] As a result of their attempts in this extra airplane lab these boys are now planning a career in aeronautical engineering; specifically in flight test work. One of them is now building radio controlled models.

Some students act as timers, while others act as distance measurers and recorders. The whole event takes place in the gymnasium, the planes being launched from the balcony. Because of the novelty of the lab there is much excitement and confusion. Visitors drop in, adding their curiosity and interest. Watching the launching of the models, they ask, "This is physics?" Data is being shouted around; the launcher is jovially accused of an unfair launch; an almost carnival-like atmosphere abounds. However, the students are very busy collecting the data they have been instructed to find. As well as their airplanes' weights, which are already known, they have to find the straight-line distances of their flights and the duration of their flights.

Because the longest recorded time in the air has been 9 seconds, the whole contest does not take all that much time: 45 minutes is sufficient to complete it. The reaction of the students to this bit of "fun" has always been most enthusiastic.

The next time in class we discuss the contest and give credit to the winners. It becomes obvious upon analysis that there are certain airplane shapes that will carry an airplane the largest distance. These airplanes, however, sacrifice time in the air to get that distance, reaching their destination relatively quickly. Other designs enjoy greater duration in the air, but do not go as far, often circling. When questioned, the students reveal themselves to be familiar with the differences in wingspan design between gliders and jet fighters, and they are interested to see the results of these differences as they occurred in their flight contest: those models with the shorter wings travelled the furthest and the fastest; the models with the longer wings moved more slowly but stayed up a relatively long time. The students have discovered that no one model can satisfy both goals of travelling the furthest plus remaining in flight the longest.

The students' analyses also show that the heaviest models have gone the farthest, having better "penetration". As an analogy I go through a calculation for the students where I show that if a large jet airliner were to shut off its engines at 40 000' over Ottawa, it could glide all the way to Montreal. The problem here is identical to the one the students have participated in but it is obviously much more spectacular. In the 25 minutes it takes to go the 100 miles distance, a jetliner would convert its potential energy into heat due to the friction of the air, an energy exchange rate that amounts to 1 400 H.P. Here again is a case where horsepower is required to fly a plane, but it is being supplied not by an engine, but by the loss of potential energy over the time it takes the jet to descend. To my amusement, students do not readily accept this view, yet they ultimately acquire some feeling for it, especially in view of their calculations of the horsepower required to fly their own planes, a meagre 2/1 000 H.P. In this airplane lab, the students have had to grapple with work-energy relationships, with losses due to friction, and they have had to accept the fact that their gliders required power to fly themselves. As a demonstration of the principle of the conservation of energy in a gravitational field, the lesson has been a success.

From this introduction, the students go on to face Experiment No. 32, now accepting it for what it is: another look at some energy exchanges. The only new idea is that there are three energies instead of two that have to be accounted for. The frame of mind of the students after the model flight lab is so much improved, so much more receptive toward Experiment No. 32 now than was ever the case in previous years before I introduced the airplane lab, that it seems a pity it is not part of the official PSSC course. I do not think students find the graphical analysis of Experiment No. 32 any easier than before, but it has been my experience that not only are they more willing to wrestle with it now, but also "energy exchanges" definitely means something more to them by the end of the year than it did before. Certainly by Piaget's yardstick this should be our aim.

Demonstrations Following Experiment No. 32, "Changes in Potential Energy"

Experiment No. 32 tries to give the students an awareness of energy exchanges between potential and kinetic energy. It does so, however, strictly within the laboratory context. Although the students, with the help of my pre-lab, are indeed better aware now of the scope of energy exchanges, they still benefit from further examples I introduce after Experiment No. 32. Whereas my pre-lab deals with interaction with the principles involved in Experiment No. 32, and as such serves to clarify the PSSC experiment, these post-lab exercises attempt to show how a familiarity with its principles can be useful in daily life. The emphasis is on the relevance to particular life concerns.

The first exercise actually began as a spur of the moment affair when, during a classroom analysis on the conservation of energy, our discussion led us rather accidentally into an intriguing bit of investigation. We had been talking about energy wastage when an issue which had been simmering in the back of my mind over a period of many months came to the fore. It had to do with the extent of energy wasted at stop signs on city streets. My class picked up the cue and together we calculated the energy required to accelerate my car to the legal speed limit in our town. We multiplied that by the number of stop signs I had to pass on my way to work and derived the figure for the energy consumed to start and stop my car. This number was extrapolated for the number of cars and stop signs in the city of Montreal and led to an incredibly large number of gallons (60 000) wasted at this city's stop signs. The whole exercise was an eye opener to the students.[1]

---

[1] It seems it was an eye opener as well to the general public. The classroom discussion spurred me on to write an article on the subject (See Appendix C) which appeared in a local newspaper and then was picked up for broadcast over the national CBC radio network. Both these arenas produced considerable lively feedback.

Not only was this relevant and useful information to have from a practical, economic, sociological[1], and an ecological point of view--and we went on to discuss these aspects--but it impressed on them how closely related physics is to everyday life, and how the tools of physics can be made to serve the real world.

The next exercises to which I expose the students are intended to further enlarge their appreciation of energy exchanges. To deal with these exercises I invite the school's ecology teacher to join me in my classes to discuss the many <u>chemical</u> potential energy exchanges involved in man's food cycle.

The ecology teacher reviews with the students the idea that the human body needs food to operate. This food, a form of potential energy, is stored in the body's fat. Where, he asks, does this food come from? The students invariably refer to the food source: food is grown, either in plant or animal form. At this point the ecology teacher takes what the students ultimately find a startling approach to the subject: "How much energy is burned from the time the food is produced to the time it is put on your table?" The students have not thought of this question before; for them, their food chain really begins at the grocery store.

---

[1] As a part of the discussion on the sociological implications of this information, students appreciated the quandary of having to weigh the pros and cons of energy wastage versus the lowering of traffic speeds by the use of multiple stop signs.

Having turned their minds in this direction, the ecology teacher introduces his environmental approach to physics by showing slides of energy consumption in the primitive societies of New Guinea and Nigeria. Students are intrigued to learn that in primitive societies one calorie of energy expenditure in labour results in 15 calories of food, whereas in our technological society 3 calories are expended to derive 5 calories of food.[1] (An interesting philosophical discussion usually develops at this point concerning the relative efficiencies of the two types of societies.)

As an example of our society's values concerning this productivity ratio we investigate a box of corn flakes. The production of corn flakes is an excellent example of what our technological society can allow itself to do with regard to its food production. The student learns, for example, that corn flakes were developed by the Mormons as a non-food, to be consumed during their religious fasts.[2] This surprises and impresses them. (In a similar manner students are impressed by the misleading labelling on the box of corn flakes we see in the store: "24 grams of protein[3] per 7 oz. of flakes"--an example of the deliberate mixing of units aimed at the unwary to

---

[1] Mr. J. Lieber, the ecology teacher. His information was obtained from United Nations data on world food production.

[2] Mr. J. Lieber

[3] In an attempt to qualify corn flakes as a food it has been necessary to add minute quantities of a "food"--in this case the choice has been protein.

present a favourable ratio. In fact, by calculation it turns out that over three 14 oz. boxes of flakes--a total cost of $1.50+--would have to be consumed daily if the flakes were the only source of protein.) After determining how many boxes of corn flakes can be shipped in one truck, it is then determined that 0,07 gallons of gasoline have to be burned to deliver just the one box from London, Ontario to Montreal. The transport of the box consumes $2x10^3$ kilocalories of energy, whereas it yields only $2x10^3$ kilocalories of food energy. The return is equal to the input. Disregarding the added energy output involved in picking and processing the corn, packaging it, marketing it, buying it, and so on, all of which further diminish the system's efficiency, it is costing in energy as much just to transport it to my breakfast table as it is giving me back in energy when I eat it. This particularly blatant example of our society's productivity ratio staggers the students. The box of corn flakes has served merely to open the discussion to energy exchanges. But now that the students see the need for their investigation they react eagerly when, as a physics exercise, they are asked to trace with the help of the formulas in their textbook, their daily actions in terms of energy consumption. (See Appendix D.) Their concepts of energy exchanges have undergone some refinement since completing Experiment No. 32.

The ecology teacher next picks up the thread of an idea contained within the food production lesson: that of measurement and the need for care in handling measurement data.[1] Though this subject is an aside to the PSSC course, I like to retain these sessions as an adjunct to the course for the very reason that they do reinforce in a strikingly relevant way what we are trying to teach our physics students throughout the year: that they must record and interpret their data with the utmost care and scrupulosity. (For a description of these sessions, turn to Appendix E.)

During these 3 or 4 sessions with the ecology teacher, students have had an opportunity to put the physics material they are learning into a context important to their growth as individuals; they have been able to use their physics in a look at the quality of life. This opportunity to encourage within them a point of view of their physical world seems to me to be an important step in any physics course.[2]

---

[1] See the reference to the deliberate mixing of units, p.81.

[2] An interesting sidelight to this cooperative project is that for one series of occasions I visited the ecology teacher's classes in an attempt to enrich those classes by looking at how physics relates to ecology. We believed that physics is not an isolated entity, but linked entirely to the environment. On the whole this project proved unsuccessful. His classes were at the grade 8 level and it soon became evident that children 13-14 years of age simply were not ready to have a sophisticated look at the various interdependent relationships of life. At least by the particular methods that we chose at that time, it appeared that there was an optimum time for such an integrated look at the world, one dictated by the maturity and experience of the students.

Obviously, this lends credibility to Piaget's theory of the learning stages. The grade 8 students had not yet reached the formal operational level, nor were they likely yet capable of utilizing logical-mathematical operations on such new subject material as that which we were attempting to bring them.

It is a pity we had not been introduced to Piaget before making the attempt.

Whether similar collaborations would be capable of introduction into most schools' PSSC programmes is questionable. A majority of schools would likely have no ecology teacher for one thing, and no administrative provision for such collaboration for another. However, it seems to me that a similar "time-out" for expansion from the human point of view on one of the PSSC themes--energy is a particularly apt choice--is both capable of being written into the course, and important enough to do so. The exercise provides, after all, both concrete reinforcement of pertinent subject matter as well as encouragement toward an "overview" of the physical world--the very aims which have been the moving force behind all my modifications of the existing PSSC course.

These, then, are the additions I have made thus far to the PSSC programme. The additions I have described are, quite naturally, those which have stood the test of just over 3 years of use by various PSSC physics classes. Not every idea I had succeeded in the classroom: those which seemed in their first attempt to fall short of my goals, I dropped. The additions which remain seem to me to be those which most successfully were aimed at the students' capabilities. After some 3½ years of experimenting with various kinds of additions I am more than ever convinced of the importance of "knowing your student and his capabilities" when designing a study course. Only in this way can the learning material be accurately aimed to produce a successful learning experience. I feel that without the additions I have described, or others like them, the PSSC course as it stands misses its aim rather too often, and leaves the student behind. Inserting my additions into the course seems to be sufficient to bring the PSSC curriculum and the students to whom it is aimed into proper alignment.

VI

STUDENT RESPONSE TO THE PSSC ADDITIONS

In order to determine just what effects my additions have had on my PSSC students I have gone directly to the students for their impressions of the course and of how they have interacted with it. I also have considered my own observations of their performances, comparing these to the performances of the students I had before I began my additions programme.

In order to hear what the students have to say, I have been issuing questionnaires to them since the year 1973 when I began developing my modifications. They receive their first questionnaire (see Appendix F) when they enter the course in the fall. The questionnaire obviously does not look for reactions to the course, since the course is just beginning. Instead, part of its purpose is to provide data concerning the students' aims and skills against which to compare the data from the end of the year. It also is intended to satisfy myself of the kind of student I am dealing with, so that I might be better guided in designing my additions to the programme. Knowing that the PSSC course ostensibly has been designed with a view to preparing the more capable student to progress to advanced study in modern physics, it is crucial to me that I determine from the outset and before implementing and evaluating my additions if indeed I am dealing with the relatively superior student. Whereas in the years prior to the additions my students experienced some major difficulties in coping with the abstract PSSC material, it seems reasonable to assume that, if the students are superior intellectually, these problems should be capable of being rectified by providing my concrete material as a preliminary step to the more abstract PSSC material, a step, which, once taken by the students, should lead them with greater assurance to the PSSC levels. For this to be so, however, the students would have to be capable already of formal operational thought; in other words, they would have to be relatively superior intellectually. Enlisting Piaget's views, (1964: 180) no amount of additional material would be capable of leading the student who is as yet "locked in" to concrete operations to the higher abstract operations expected by the PSSC curriculum. The purpose of any of my additions must be to provide concrete activity when the PSSC course demands formal activity of students who for that particular subject area have had insufficient prior concrete experience to enable them to handle the subject on a formal level.

For this reason I must know if the students in my course are indeed relatively superior and predisposed toward learning.

The responses to the questionnaire (for an evaluation of these responses, see Appendix G) indicate that indeed the PSSC students do seem to be intellectually superior. This information is reassuring. If the students enrolled in my PSSC courses had in fact revealed themselves to be average or below average intellectually, any attempt on my part to provide useful additions to the relatively formal PSSC curriculum[1] would have been futile. A look at the answers, however, confirms that at least my additions have a potential for being useful.

The questionnaire I issue in May[2], (see Appendix H) at the end of the school year, asks the students whether their goals for taking the course have been fulfilled, and how in general they have reacted to the course. When this questionnaire is distributed the students are not shown their responses to the previous fall's questionnaire. This is to ensure that when they reply to the question concerning their motives for taking the course, and whether those motives have been

---

[1] See pp. 42-44

[2] At the time I originated the questionnaire I had no idea of using its information for any purpose other than my own illumination. Since I was personally well satisfied that my PSSC classes prior to my attempt at modifying the course had encountered sufficient obstacles throughout their year to cause discontent, I made no special effort in my questionnaire to isolate my own additions for student comment, thinking that most positive reaction to the course in total would indicate by itself a "change" in attitude toward the PSSC course. I, of course, would interpret this change as being as a result of my additions, since nothing else had changed, neither student ability, (as my fall questionnaire had shown) nor the PSSC course itself, nor, indeed, the teacher. This approach may have been sufficient for my own purposes, since I was thoroughly familiar with how my previous students had fared without the additions, but I recognize that for the purposes of this paper it would be infinitely more satisfying if the questionnaire had included specific mention of my additions. However, once the questionnaire was in operation I felt that for the sake of continuity and valid comparison of responses from one year to the next, I had better retain the questionnaire in its original form. There are, as we shall see however, enough unsolicited references made to my additions by the students to justify a look at their responses here.

fulfilled, their responses might better reflect their actual thinking at that time.

Most of the students in their answers to my questionnaire seem to retain an idea of their goals in the course consistent with what they originally thought those aims to be. Approximately 95% feel the course has fulfilled these requirements. (See Appendix I.)

The question "Have your motives for taking physics been satisfied?" has on occasion, however, produced answers which begin in the negative and then in their elaboration continue in a vein suggesting that their answer really is positive. For example, "No, I find now that I want to continue my education in physics so I can learn more." The elaboration suggests that the student has found physics interesting enough to want to pursue its study--definitely a positive feature. Yet he has answered, "No". Recognizing that the question leaves room for this kind of confusion in the answer, it still has been necessary in order to retain continuity throughout the three years to retain the faulty question as well. I have had to settle instead on interpreting the answers whenever necessary, in such a way that the type of answer outlined above can be accepted as a "Yes" rather than a "No" answer.

In connection with the students' response as to the relative values of various parts of their total physics exposure one must note the responses to question no. 3, (see Appendix J) "Which of the activities did you find most beneficial toward realizing your goals?". This is a direct question to the students which demands that they look at their personal objectives, and then the course, and give a statement which is a kind of evaluation of the course's general relevance to their own needs.

The responses to this question no. 3 are generally identical for all four of my PSSC classes. The breakdown of what has been considered most useful by the PSSC students is as follows:[1,2]

Labs	Class Discussion	Demonstrations	Reviewing Problems	Text Problems
45%	25%	25%	2%	2%

It is difficult from the responses given by the students to determine what they mean when they write "labs" as the most beneficial activity. Although some students mention my additional labs specifically, (for example, "Atomic Physics and paper airplanes", "The paper airplane and other extra labs") do the other students mean the PSSC labs, the extra-labs, or both? This is unclear. However, later on in answer to question no. 9 (see Appendix H) a Physics 552 class mentioned that they would have

---

[1] The terms used in the headings are the students' own, having used these terms in their answers.

[2] Whereas half the students claim they have taken the course to satisfy CEGEP entrance requirements, it is interesting that none of the responses to this particular question mentions class tests, exam reviews, and exam preparation sessions held, which would have served the students most directly in that respect.

liked more labs. This happened to be a particular class which, while I was still developing my extra-lab programme did not get my full repertoire of extra-lab work. As opposed to 22% of those PSSC classes receiving the complete extra-lab programme who indicated they would like to have more lab experience, 65% of the students in that "deprived" class desired more labs. It would seem the "deprived" class felt more keenly the lack of sufficient additional lab material. Correlating this information with that from question no. 3 it is reasonable to assume that my extra-labs were found useful. Certainly it is accurate to say that students generally seem to sense that lab activity is of most use to them.

"Class discussion" most probably relates to these occasions when highly active interplay between student and teacher occurs on a particular point, or when there is a spontaneous controversy or debate. "Demonstrations" may again mean either PSSC demonstrations, my extra-lab demonstrations, or both. Again, however, a significant proportion of students specify my added material in their answers. I presume from the comments the students make that these classroom discussions and demonstrations are thought of as separate from the general lesson presentation. Students feel they thrive on these occasions when I appear to deviate from my planned material and launch into an aside, though as shown in the last chapter, some of these "impromptu" excursions have in fact been premeditated as part of my extra-lab activity. It is likely, however, that when they feel an activity is impromptu they feel at the same time that they are participating more fully; they are part of a real happening. A large percentage of students preferred this "natural" form of concrete activity.

To question no. 4, "Which of the activities throughout the year do you feel were irrelevant from the point of view of your goals?" 22% of the students had no comment. 42% replied, "None". If it is assumed that the 22% who left a blank after the question did so because they had no strong feelings about anything having been irrelevant, this would in fact mean that 64% of the students answered, "None". 14% mentioned wave motion and light. However, of this 14% response, 10% came from students in grade 10 452 classes[1] and the remaining 4% came from the grade 11 PSSC classes. In the grade 10 PSSC 452 class virtually the whole first half of their year (5 months) is spent on the topic of wave motion and light, as opposed to the first quarter of the grade 11 year (2½ months) spent on the same subject. It is not surprising then that having to spend such a major portion of their year on what all PSSC students find a very difficult topic leaves many in the Physics 452 class somewhat disenchanted. Not only do they spend more months on the subject, but at no

---

[1] This class, it must be remembered, studies the PSSC course over a period of 2 years, unlike all the other PSSC classes which take just the one year to complete the curriculum.

time in their year do they have the opportunity to see the application of its principles in atomic physics which is featured at the end of the PSSC course--in their case, the end of the following year, after they answer this questionnaire. By the time the grade 11 PSSC students answer this questionnaire they already have studied atomic physics, and thus have had an opportunity to realize that their earlier wave motion study can have its relevance. For these reasons it is perhaps invalid to include the Physics 452 answers to this particular question, at least insofar as the answers pertain to wave motion.

Another activity coming under fire is the work centred around the PSSC textbook--some 14% chose it as being irrelevant to their goals. 10% specified the text's exercises were irrelevant, and the other 4% complained of the actual reading of the text. Interestingly enough, the percentage from grade 11's alone who fail to appreciate the text is not lower, as one might expect, but higher than the overall percentage: 19% of the grade 11 PSSC students are dissatisfied with it. (This mirrors the data derived from question no. 10, "Suggest what you would like to do less", where, apart from the 47% who would not change anything, the only activities which received a vote higher than 9%--which referred to tests--were the activities of reading and working on the textbook exercises: these received a vote of 23%.)

With such a large percentage (64%) agreeing that none of the course was irrelevant, and miscellaneous "irrelevant" items spread about to take up 8% of the votes, and wave motion and light perhaps being disqualified as a source of irrelevancy or at least reduced to a 4% vote (due to the circumstances mentioned above) this leaves the PSSC text in the somewhat dubious position of being winner of the irrelevancy award. Definitely the students are least stirred by abstract book work, and as the high percentage expressing satisfaction with the course would indicate, they do find lab and other concrete activities useful.[1] Data from this question, then, supports the data collected from question no. 3, discussed a moment ago.

Question no. 13, "How do you feel about the demonstrations?", was aimed directly at the background and fill material for the labs and theoretical work in the text as they were provided in the PSSC Teacher's Guide and also by my own additional demonstrations. Comments on this question were candid:

"I really liked the demonstrations and felt I learned more from them than the lessons." (Again, note the implied separation of demonstrations and lessons.) "Fine." "I wish there were more." "Good, informative." "A great way to learn and appreciate a fact--not enough!" "Very helpful." "Easier to understand than reading."

---

[1] This information is not at all surprising and in fact supports the PSSC curriculum's emphasis on lab activity.

Other than that there were not enough, there was not a single negative comment concerning the demonstrations: either those suggested by the PSSC Teacher's Guide or my own. In a sense that is curious since not all my demonstrations were equally successful and a number which were spur of the moment affairs did not involve the students other than as observers. Yet, as mentioned earlier, students apparently much appreciate the feeling of spontaneity which is possible to create in demonstrations--even those which in fact have been planned. There is a kind of excitement in a class when an argument is started (often deliberately), everyone becomes embroiled in it, and an experiment is set up to prove and settle things to everyone's satisfaction. The responses to this question again reinforce the data from question no. 3, wherein I concluded students highly appreciate this natural form of concrete activity.

There is no doubt left by the students' answers to their May questionnaires that they have responded most positively to concrete activity as a means of learning. This response can only confirm that the PSSC course's emphasis on lab activity is appropriate. The students found this emphasis satisfying and pleasurable, often to the extent of motivating those who were not thus motivated before to consider further physics study in the future. As well, and included in this appreciation, there have been a significant number of responses specifying that my additional work has been useful. The students have claimed both to have enjoyed the additions and benefitted from them.

It remains to look to my own impressions now to see if they confirm what the students have said. In order to judge how the students in fact have responded to my work, I have taken care to observe their overt reactions as well as their actual performance with the additional material. At all times it has been necessary to judge how those reactions and performances have compared to students' reactions and performances before I began adding material. Certain questions have had to be answered: for example, are the students enjoying their learning material?[1] In those areas where originally my students were experiencing difficulties with the existing PSSC course: are the students now succeeding in their assignments? Are they answering synthetic questions thoughtfully and intelligently? Are they asking pertinent and thoughtful questions? Are they retaining what they are learning? Are they showing they can apply their new knowledge in new areas? In other words, can they be creative with their new knowledge?

Through general observation, personal interaction with the students, and through evaluation of the students' laboratory performance I have been able to determine that those students to whom I have taught my enriched PSSC course have

---

[1] This question of enjoyment is not as superficial as it might seem. It is significantly linked to the subject of motivation, which as we have discussed before is necessary for "real learning" to occur.

achieved more satisfactorily as a group in all areas of questioning mentioned above than have those students as a group to whom I have taught the official, unadorned PSSC course. It is my assumption that it is the additions which account for the differences, an assumption not altogether too presumptuous, since it is improbable statistically that over the 3½ year period in which I was developing my modifications I was dealing consistently with students of a higher operational level than were those I taught prior to my innovations. Indeed, student responses to fall questionnaires seem to indicate that the course attracts a uniformly high calibre of student each year. Further, when my additions followed rather than preceded a troublesome PSSC area, the students who took my enriched course experienced the same kinds of problems in performing and analysing the PSSC experiments, or the same absence of real learning as had my former PSSC students. Once the post-lab additions had been handled, however, most of these problems were solved quite satisfactorily.[1] Certainly, in talking and otherwise interacting with all my students, those "before" and "after" my additions, it is my distinct impression that those students who have been exposed to my additions have acquired a "feel" for physics, its aims, its language, and its problems that is of quite a higher order than have the others.

---

[1] See pp. 68-71, 78-82

Judged, then, from both the students' point of view and from my own observations, my extra-labs have helped to provide the proper environment for real learning to occur. They have ensured an opportunity for concrete, relevant activity which has enhanced the PSSC programme for my students significantly.

CONCLUSION

Five years have gone by since I started teaching the PSSC Physics course and in that time I have taught 20 PSSC classes. Approximately 12 of these have been exposed to my extra-lab programme. No two of these classes have been the same, yet they have all been enjoyable, and in my view, successful. However, what effect I have had on the students individually I will never know.

By the definition of the purpose of my enrichment programme, to maximize the learning potential of the student, my programme exists to enhance the students' learning and development. The full effects will not appear until some time in the future and at that point cause-effect relationship will be difficult to retrace. As well, if Piaget is right, intellectual development is age dependent so that the overall effect of a specific activity on the student's operational level may not be measurably altered in the year or two during which the student is exposed to my enriched programme. Yet the programme may have been profoundly effective.

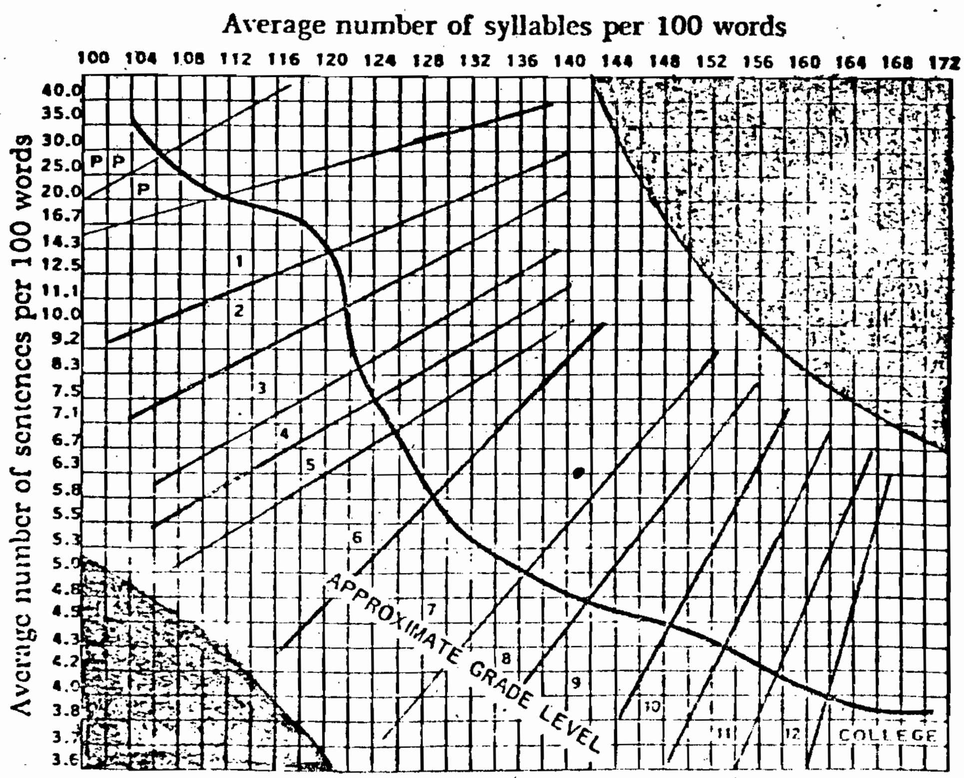
In every class of every year there have been successes and failures. On the negative side have been my own feelings of not having tried as many things with the students as I would have liked, sometimes because of student disinterest, sometimes because of my own personal preoccupation. There is that feeling of, "Did I aim for too much?" "Have I settled for too little?" Yet I do have the feeling that the enriched classes have been more meaningful and enjoyable to my students as well as myself than the PSSC course was without the extra-labs. The programme, moreover, has worked, and the students have been interested. Yet I recognize that others attempting the same extra-labs might not experience the same results, given different schools, social backgrounds, and a different teacher.

The only concrete evidence of the success of the extra-lab work which I can offer is the evidence of my students' behaviour: how they behaved during my enrichment sessions as opposed to how they behaved before I began to provide this extra work. Their increased familiarity with the apparatus and with relevant ideas, gained in the extra-lab situations, appeared to greatly enhance their interest and efficiency when the students were asked to investigate and generalize a subject further.

Since I believe this type of reaction to be related to real learning, I am satisfied that my extra-lab programme has served a useful purpose in encouraging the processes of equilibration and cognitive development in my students.

APPENDIX A

GRAPH FOR ESTIMATING READABILITY - Ed Fry



DIRECTIONS: Randomly select 3 one hundred word passages from a book or an article. Plot average number of syllables and average number of sentences per 100 words on graph to determine the grade level of the material. Choose more passages per book if great variability is observed and conclude that the book has uneven readability. Few books will fall in gray area but when they do grade level scores are invalid.

		SYLLABLES	SENTENCES
EXAMPLE:	1st Hundred Words	124	6.6
	2nd Hundred Words	141	5.5
	3rd Hundred Words	158	6.8
	AVERAGE	141	6.3

READABILITY 7th GRADE (see dot plotted on graph)

If passage is less than 100 words in total, count the number of words, sentences and syllables then put into the following ratio: $\frac{100S}{W}$ = sAPH.

Where S = sentences or syllables. W = number of words. sAPH = the number of sentences or syllables as per hundred words.

Sample: 45 words; 63 syllables; 28 sentences.
syllables sAPH = 131; sentences sAPH = 5.3; grade level = mid 7.

For further information and validity data see the April, 1968 Journal of Reading and the March, 1969 Reading Teacher.

Analysis of an Experiment

1

The presentation and analysis of experimental results is an essential part of physics. In Table 1 are the results of an experiment. You are asked to present and analyze these results in a form which will enable you to predict the outcome of similar experiments.

The experiment was an investigation of the time it takes water to pour out of a can through a hole in the bottom. As you would expect, this time depends on the size of the hole and the amount of water in the can.

To find the dependence on the size of the hole, four large cylindrical containers of water of the same size were emptied through relatively small circular openings of different diameters. To find the dependence on the amount of water, the same containers were filled to different heights.

Each measurement was repeated several times, and the averages of the times (in seconds) that each container took to empty have been entered in the table. A stop watch operated by a human hand cannot be trusted to measure less than a tenth of a second. The last digit in each time entry in the table may be in error by one unit either way. Therefore, the relative (or fractional) error is larger for shorter times than for longer times.

	h *in cm*			
d *in cm*	30.0	10.0	4.0	1.0
1.5	73.0	43.5	26.7	13.5
2.0	41.2	23.7	15.0	7.2
3.0	18.4	10.5	6.8	3.7
5.0	6.8	3.9	2.2	1.5

Table 1
Times to Empty (sec)

All the information we shall use is in the table, but a graphical presentation will enable us to make predictions and will greatly facilitate the discovery of mathematical relationships.

First, plot the time versus the diameter of the opening for a constant height, say 30.0 cm. It is customary to mark the independent variable (in this case, the diameter d) on the horizontal axis and the dependent variable (here the time t) on the vertical axis. To get maximum accuracy on your plot, you will wish the curve to extend across the whole sheet of paper. Choose your scales on the two axes accordingly, without making them awkward to read.

Connect the points by a smooth curve. Is there just one way of doing this? From your curve, how accurately can you predict the time it would take to empty the same container if the diameter of the opening was 4.0 cm? 8.0 cm?

Although you can use the curve to interpolate between your measurements and roughly extrapolate beyond them, you have not yet found an algebraic expression for the relationship between t and d. From your graph you can see that t decreases rather rapidly with d; this suggests some inverse relationship. Furthermore, you may argue that the time of flow should be simply related to the area of the opening, since the larger the area of the opening, the more water will flow through it in the same time. This suggests trying a plot of t versus $1/d^2$.

To do this, add a column for the values of $1/d^2$ in your notebook and, again choosing a convenient scale, plot t versus $1/d^2$ and connect the points with a smooth curve. What do you find? Was your conjecture correct? Can you write down the algebraic relation between t and d for the particular height of water used?

To find whether this kind of relationship between t and d also holds when the container is filled to different heights, on the same sheet of graph paper plot the graphs of t versus $1/d^2$ for the other heights. What do you conclude?

Notice that the graph for $h = 1.0$ cm extends upward very slightly. Make a special plot of these data on a larger time scale so that you will use the whole sheet. What do you observe? On the basis of your data, what can you say about the algebraic relation between t and d for $h = 1.0$ cm?

Now investigate the dependence of t on h when the diameter of the opening stays fixed. Take the case of $d = 1.5$ cm, which is the first row. Make a plot in which h will be marked on the horizontal axis and connect your points by a curve. Extrapolate the curve toward the origin. Does it pass through it? Would you expect it to do so?

How can you use your plots of t versus $1/d^2$ to predict t for $h = 20.0$ cm and $d = 4.0$ cm?

There is no simple geometric consideration to guide us to the right mathematical relation between t and h. You can try to guess it from the curve. It may be helpful to rotate the graph paper through 90° and look first at h as a function of t, and then at t as a function of h. If you succeed, check by proper graphing to see if the same kind of relation between t and h holds for $d =$ 5.0 cm.

If you are familiar with logarithms, you can check to see if the relation belongs to a general class of relations, such as a power law, $t \propto h^n$. To do this, plot $\log t$ versus $\log h$ (or simply t versus h on log-log paper). What do you obtain? What is the value of n?

Can you find the general expression for time of flow as a function of both h and d? Calculate t for $h = 20.0$ cm and $d = 4.0$ cm and compare the answer with that found graphically. Which do you think is more reliable?

2

32 Changes in Potential Energy

Hang a spring from a ringstand and attach a mass of about one kilogram to it. Lift the mass a few centimeters above its rest position and let it fall. At the top and bottom of its motion it is at rest. When the mass is at the bottom of its motion, its energy is stored in the spring. At the top of its motion its energy is stored in the gravitational field. Compare the change in gravitational energy with the change in potential energy stored in the spring.

You can find the change in potential energy of the spring when it is stretched a distance Δx from x_1 to x_2 by calculating the work done in stretching it from x_1 to x_2 (Fig. 1). The change in gravitational potential energy when the mass falls this same distance Δx can be found by calculating the work done in lifting the mass through the distance Δx. You can then compare the gravitational energy lost as the mass falls from rest to its lowest point with the spring energy gained as the spring stretches.

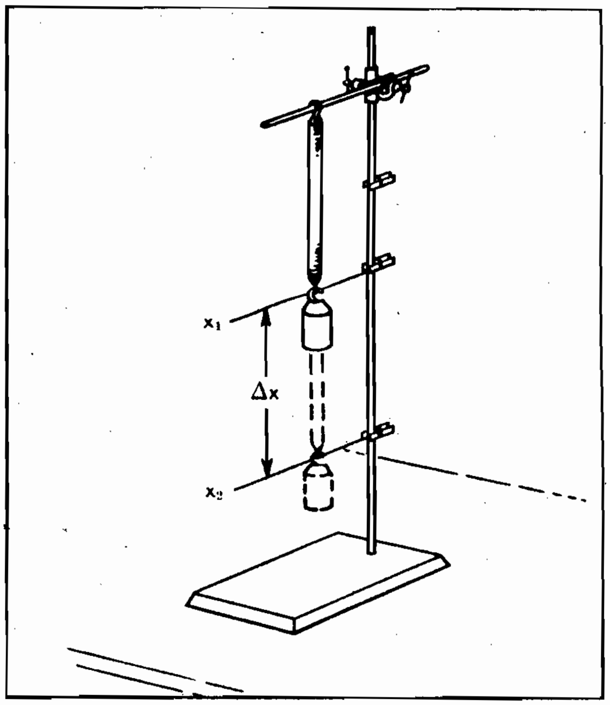


Figure 1

To find the potential energy of the spring, we first find how the extension x of the spring is related to the force that stretches it. (If you are using the same spring as in Experiment 25, you may use the information you obtained then.) Hang known masses up to a maximum of about 1.5 kg on the end of the spring and find the extension x in meters as a function of the force F in newtons. Plot a graph of x as a function of F. Is F proportional to x for this spring in the range of your measurements?

If your graph is a straight line, find the spring constant $k = \frac{F}{x}$ from the slope and write down the potential energy function of the spring; that is, the equation for the energy stored in the spring as a function of the extension of the spring. How can you find the potential energy stored in the spring for a given extension if your graph is not a straight line?

Now hang a one-kilogram mass on the spring and support it with your hand so the spring extends about 20 cm more than its natural length when hanging without the mass. Use clothespins clamped to the ringstand to mark the lower end of the unloaded spring and the point from which you drop the mass. Release the mass and note how far it falls. Place a clothespin on the stand to mark the lowest point of the fall. Release the mass several times until you have accurately located the lowest point of the vibration.

Calculate the loss in gravitational potential energy and the gain in potential energy of the spring when the mass falls. How do they compare? Repeat the above experiment, releasing the mass from a point about 25 cm from the lower end of the unloaded spring. Repeat the experiment with a 0.5 kg mass and calculate the change in gravitational potential energy and spring potential energy when the mass falls from a point about 10 cm below the end of the unloaded spring.

Is energy conserved in these interactions between the masses and the spring? Are they elastic interactions?

What is the sum of the two potential energies when the kilogram mass has reached the halfway mark in its fall? How does this compare with the initial energy of the mass? How do you explain this? How could you check your explanation?

If you have time, plot a graph of the sum of the two potential energies as a function of the spring extension. What can you learn from this graph?

APPENDIX C

A commentary

The energy-waste aspects of stop signs

by Frank Hofman

Much has been said and written in recent years over the aggravating problem of traffic control and the proliferation of stop signs throughout our local municipalities.

By simply looking around it's plain to see that those in authority in our local municipalities have no real grand design, or even basic policy when it comes to the placement of stop signs. What seems to exist is a traditional practise of mindlessly erecting a stop sign wherever and whenever the city has received a sufficient number of complaints. This inevitably leads to the city being forced to erect still more stop signs to thwart the motorists seeking to avoid the first stop sign.

This explains the jungle of stop signs we find in all our local municipalities, and accounts in large part for the profound contempt in which the stop signs are held by local motorists. The obvious better way, of course, is to have a minimum of stop signs, but have them kept under close surveillance by the police, with heavy penalties for offenders. People would then respect the signs because they would recognize they made sense and were justified, a prime requisite for the observance of any law. But those who did not soon would, after feeling the heavy hand of the law.

There is another aspect to this mindless business to which nobody ever gives a thought – the needless, unconscionable waste of our declining, irreplaceable and increasingly expensive energy resources.

Let's just take a look, through some rough calculations, at the extent of this waste:

If we agree that the automobile's share of the energy budget, (13%), is significant enough to warrant legislative action (e.g. lower speed limits), then, to be truly honest and concerned, we should look also at other situations involving the automobile which are deserving of moves to economize. But what has been done? By industry? governments? people? you? me?

Let us assume that one gallon of gasoline contains 1.4×10^8 Joules of energy. It can be calculated that an 1800 Kg car accelerated to a speed of 12 m/s (12 m/s = 30 m.p.h.) from a stop requires the input of 1.4×10^5 Joules.

If the system were 100% efficient, the fuel consumed per stop would be 1×10^{-3} gallons. However, because the system is only about 10% efficient, one gallon yields only approximately 100 stops and starts.

On driving 7 miles to work and home daily, I go through 42 stops, almost all of which, (36) exist apparently to slow traffic. For me this means that 2½ gallons are wasted per week simply for stopping and starting, not counting the cost in fuel of making and delivering replacement brakes, clutches etc., and the fuel expenditures of the people involved in the handling of these. Yet city planners mindlessly proliferate sprawling suburban settlements in an effort to serve the people on this planet. (?)

To look at the overall effect of untimed lights, needless stop signs, and poorly developed mass transit systems, let us look at the fuel waste for a city of 2,000,000.

In my section of the city there are 21 stops in 7 miles. Assuming that is representative of the whole city, the 1400 miles of road in this city should have 4200 stops. If we assume that only 20% of those are really necessary (having mass transit), we get to the number of 3,300 needless stops.

Assuming that there are 300,000 vehicles in operation, and that each vehicle travels 7 miles a day, one can project 6,300,000 needless stops per day. At 100 stops per gallon, that means 63,000 gallons wasted directly in a day, aside from other indirect associated costs in fuel!

Where are our leaders leading us?

Mr. Hofman is a science professor at Beaconsfield High School and resides in Pierrefonds.

APPENDIX D

Students' Daily Energy Consumption Exercise.

Students are given instructions to determine how much energy they consume in a day. Before beginning we list some of the more obvious ways energy is consumed. At home the students find out how much food they consume, measure this in kilocalories, and convert their findings into Joules. They also retrieve the electricity bill for their home and calculate from that the number of Joules of energy they might have consumed per day during that period. From an estimate of the number of gallons of gasoline burned by the family car they deduce an amount which might have been spent by themselves individually in a day. They average the heating bill for their homes for the year to arrive at a consumption rate per day per person in their house. Finally I give them the heating and lighting costs and consumption for our school, which they take to derive a number per student of the energy consumed there. (The fact that each student does not spend the entire day in his home as well as in the school does not alter the fact that these buildings are maintained even during the hours the student may be away.) The total consumption is a huge number, somewhere in the order of 7×10^8 J/day per person. That number is 100 times the rate required to exist at a minimum level, and does not include all extraneous energy consumptions, too numerous to consider but very much a real part of the students' daily life. Obviously the students are impressed by this information, particularly when they compare the numbers for individual energy consumption in New Guinea and Nigeria to their own. Inevitably some collective soul-searching ensues as to the relative merits of the differing life-styles.

APPENDIX E

Lessons on Data Gathering

The ecology teacher, enlarging on the idea of objectivity and care in data gathering, spends time discussing the use and misuse of statistics and sampling. He comes prepared with some newspaper advertisings. The class becomes involved in analysing various examples from the paper, some of which stand out more than others. On one such occasion it was a toothpaste ad which captured most of the attention. It claimed that 3 out of 4 people tested had been cavity free after using their particular product for a period of time. The ecology teacher, having spent some time in New Guinea, mentioned it was too bad the company hadn't "tested" its product there, since they would then have been able to claim that after using their product 4 out of 4 people showed an absence of tooth decay. What the company would not of course have pointed out was that the natives of New Guinea are blessedly free of tooth decay anyway, without the aids of any toothpastes. The students get the message. It is obviously possible with apparent validity to claim a change in anything if the original condition is not defined. As well, even if there is in fact an improvement in, for example, tooth conditions as is implied in this particular ad, that improvement is merely presumed to be as a result of a specific action, in this case the use of the toothpaste rather than the brushing action itself. The "results" of such presumptuous data gathering are of course meaningless. And in this particular case, the deception had been deliberate.

The teacher also attempts to illustrate how data can be misleading unintentionally. One of his examples falls into the category of using inappropriate interpretation for the occasion: the attempt to use the <u>average</u> kinetic energy of molecules as a measure of temperature. Students readily understand that the average is meaningless if they were to have, for example, one foot in 0 degree C water and the other in 80 degree C water. Their brains would not register 40 degree C to the nervous system. Statistics which can be perfectly meaningful in some instances can be equally meaningless in others.

APPENDIX F

The following questionnaire is given students at the beginning of the school year:

1) Why are you taking this course rather than some other physics course?
2) What have you heard about this course?
3) What have you heard about physics?
4) Are you expecting this course to be easier or harder than another course, for example English literature?
5) Who persuaded you to take physics?
6) Comment on the way you think a knowledge of physics can help you in your daily life.
7) State your weight in kg. and your height in cm.
8) Write a paragraph explaining why a ball rolls further than a die.

APPENDIX G

A Summary of Student Responses to the September Questionnaire

The fall questionnaire is issued to PSSC and Regular 512 Physics students alike. This is done for purposes of comparison of the responses, with the intention of determining if the student in the PSSC stream is of a different type than the student in the Regular 512 stream. The results are as follows:

In answer to question no. 1, "Why are you taking this course rather than some other physics course?" 40% of the PSSC students have said they are taking it because of CEGEP requirements, 40% because they "wanted" to take it, 10% because of the course's reputation, and 10% because it represented a key to their future. It is difficult to separate those who have said they needed it for CEGEP from those who claim to need it for the future. If those two responses are in fact the same, it would appear that about 50% of the students enroll in the course for more or less the same reason, that of making a living someday in a field somehow connected with science or technology. Since a relatively large portion of the students appear to have a definite goal in mind in their physics study, it would seem a safe deduction to make that they have, then, the desire to learn the physics material which is a requisite to real learning.

The Regular 512 students as a group seem to be expecting less from their course from the outset. 22% indicate they expect the course to further them in some goal, as opposed to the 50% of PSSC students who do.

Asked what it is they have heard about physics, and how it compares with other courses, for example English literature, most of the PSSC replies have been to the effect that their physics course would be harder, among the most difficult subjects to take in the school, with lots of lab work, and that "if you have the brains, take it". The reputation also is that it is mathematical, a point which apparently causes some apprehension. It would appear then that the students expect the course to be difficult, but that they also feel they can meet the challenge. Being science oriented they choose the physics course partly out of desire and partly out of necessity.

On the other hand, the Regular 512 students seem to feel their course has the reputation for being easier than the PSSC course, and they are taking it for that reason. In those questions directed at ascertaining the level of operation of the students--for example, the question on why a marble rolls further than a die--the PSSC students' answers are on the whole lengthier, more intricate, more inclined to include diagrams, and generally more imaginative than the Regular 512 students' answers--though no more correct. This ability to entertain a greater variety of abstract thoughts within one answer suggests the PSSC students have been more in the habit of performing on the formal operational level than have those of the Regular 512 course. Though their physics is no superior to those in the Regular 512 course, their thought processes seem to be more at home in the formal realm. Using Piagetian reasoning this would seem to imply, then, a stronger readiness for formal physics on the part of the PSSC students. Since the PSSC course itself demands an ability to think formally both in its textbook reading level and in many of its experiments, it would appear from the PSSC students' responses to this questionnaire that they should be capable of coping with the course, given my additional material to help them through the more particularly abstract areas.

APPENDIX H

Questionnaire Given in the Spring

1) You took physics for a reason, stated earlier this year. Have your reasons for taking physics changed? If so, to what?

2) Have your motives for taking physics been satisfied?

3) Which of the activities did you find most beneficial toward realizing your goals?

4) Which of the activities throughout the year do you feel were irrelevant from the point of view of your goals?

5) How do you feel about the number of labs you did?

6) How do you feel about the type of write-up required?

7) What changes would you suggest?

8) How do you feel about the exercises in the text?

9) Suggest what you would like to do more of in the course.

10) Suggest what you would like to do less of in the course.

11) Are you now any less apprehensive about taking a physics course?

12) What did you find most difficult in the physics course?

13) How do you feel about the demonstrations?

14) Are you going on in physics study?

APPENDIX I

A random sampling of responses from four PSSC classes to question no. 2 of Appendix H, "Have your motives for taking physics been satisfied?"

"Yes."

"Partially satisfied."

"Partially."

"Not really."

"No."

"They have to an extent, but not fully. I would like to have had more discussion periods."

"Sort of, but I didn't understand everything."

"Yes, I passed. I found that it helped to solve questions I had all my science years."

"Yes, pretty well."

"Not really. I want to find out more about why things are the way they are."

"There were no motives."

"...I gained a lot of general knowledge and have had a lot of things I had always wanted to know, explained..."

"Not completely. I had hoped to do much better."

"Almost."

"Somewhat, but there is still so much more to learn."

"Not yet. I want to take more."

"After beginning to see just how many different fields of physics there are I'm not sure I'll be satisfied with one High School physics course."

"Yes, I got through."

"No. There is still so much I don't understand."

"Yes. I now have learned the fundamentals."

"Yes. I wanted to broaden my horizons, and I have."

"...I also took it out of sheer interest to understand how things work, why they work, and why other things don't work. I feel these motives have been satisfied."

APPENDIX J

A random sampling of responses from four PSSC classes to question no. 3 of Appendix H, "Which of the activities did you find most beneficial toward realizing your goals?

"Discussions."

"Lab work."

"Lectures and discussions."

"...things we did in both chemistry and physics and that I knew a little about."

"Teacher's discussions and demonstrations."

"Explanations and discussions by the teacher."

"Labs. To see for yourself is better than to be told."

"Labs mainly and demonstrations."

"Studying."

"Class presentation of theories and practical experimenting."

"Labs. Free discussions."

"Listening to the teacher as well as attempting problems with everyday situations."

"The lab work was imperative; I would like to see more of it."

"Mr. Hofmann's lengthy explanations cleared up some of the destruction caused by the labs."

"Class lectures, tests and demonstrations."

"Atomic physics and paper airplanes."

"Demonstrations, films, and labs."

"The paper airplane and other extra labs."

"Going over questions in class."

"Answering the questions in the book."

"Everything except light."

APPENDIX K

Indirect Consequences of the Difficult Reading Level of the PSSC Text and of Difficult Experiments in the PSSC Curriculum

The advanced reading level of the PSSC text and the difficulty of some of the more abstract experiments which complement the text material, are having consequences reaching farther than the individual student's difficulty in comprehending the subject material. They are leading indirectly to a diluting of the PSSC curriculum in this province. Because of their degree of difficulty greater pressure is exerted on teachers to adapt the course to fit the needs and abilities of their students. The only other alternative is to "teach" it as it is and risk having the students "learn" ineffectively. An immediate outcome of this situation has to be a large variation in the calibre of presentation of this programme, an effect borne out, I have found, by the great regional variations in the high school leaving marks obtained in June examinations. This phenomenon has itself led to an imposed policy governing the setting of examinations which, to come full circle, can only lead to a lowering of PSSC teaching standards and a widening gulf between those areas which register well in June examinations and those which do not.

The Quebec government must have recognized these regional disparities at the time when computerized scoring and analysis was introduced for June marks. Provincial raw score failure rates in the 1974 and 1975 results in Physics 552 and 522 were in the order of 75%. Yet there were certain boards in the province, my own among them, where the failure rate was a typical 20% in the physics examinations. This of course meant that somewhere in the province failure rates had to be higher than 75%. Probable reasons for this wide disparity have already been alluded to above. Nonetheless, that 75% failure rate was staggering. Subsequently, instructions were issued to examiners stating that there were no longer to be questions on examinations of an evaluative or synthetic nature; rather, all questions must pertain only to acquisition, knowledge, or comprehension. (See Appendix L) Also, questions must not refer directly to a lab in the PSSC curriculum.[1] Hence, examinations in future are to rank students rather than measure what they have learned.

We have, then, a course aimed at developing the synthetic and evaluative skills of students, yet we cannot set standards to measure with what success these skills are being taught or attained. In itself that need not have any negative effects. However, as is bound to happen, teachers will to some degree or other teach their subjects to the level of the examination. After all, teachers provide a service which includes, evidently, that of preparing students for entrance to higher institutions of learning which entrance is affected by the kind of marks a student receives in his final high school examinations. The examination level to which some teachers will aim their teaching, however, is in the process

[1] This directive was given verbally to those setting examinations.

of being watered down. Hence, it is not only conceivable but probable that this new directive will in fact lower teaching standards in some parts of the province. This of course creates a rather complex dilemma. We have on the one hand a course which appears to require some modification to enable students to understand it better, yet we (or I) do not wish to dilute it or simplify it in order to achieve this end; on the other hand we have a government directive calling for measures which will in fact, for many, dilute the existing course, at least while no alternate method of teaching it officially exists. Moreover, for as long as it is left up to the individual teacher to modify the course for his own students there will be a wide range of methods used--some good, some bad, some non-existant. The calibre of teaching and of learning will be most unpredictable.

What to do then? It is clear to me that the PSSC physics course must be "officially" modified in such a way as to leave the body of its material, which is excellent, intact but some of its procedures transformed so that students find them personally relevant. This relevance presupposes that the students must as well find they can interact with the physics activities on a level suited to their abilities. Providing them with good sound concrete operational material must be the aim, so that those among them who often do operate on a formal level (and there should be a major portion of them who do, since it is the superior student who is encouraged to take this course) may then go on to more fully appreciate the material as it is presented by the existing PSSC course. Providing such a modification to the curriculum unfortunately would be unlikely to affect the government directives concerning examinations, at least initially, but it would provide teachers with a definite alternate method, supposedly one that is an improvement, for teaching the PSSC course. Hopefully this would result in improved teaching practices and more effective learning universally.

APPENDIX L

GOUVERNEMENT DU QUÉBEC
MINISTÈRE DE L'ÉDUCATION
DIRECTION GÉNÉRALE DE L'ENSEIGNEMENT ÉLÉMENTAIRE ET SECONDAIRE
SERVICE DE MESURE ET D'ÉVALUATION

TABLEAU DE SPÉCIFICATIONS

Code: 220-552 et 720-552 — Année 1976

Cours: Physique 552 — Session Mai-Juin 76

RÉPARTITION DU PROGRAMME ↓ / OBJECTIFS INTELLECTUELS →	a Acquisition des connaissances (Q / %)	b Compréhension (Q / %)	c Application (Q / %)	d Analyse (Q / %)	e Synthèse (Q / %)	f Evaluation (Q / %)	Nature des items: Question directe — Dévelop.	Question directe — Objectif	Travail sur doc. — Dévelop.	Travail sur doc. — Objectif	TOTAL (Q / %)
ENERGIE											
1 Quantité de mouvement et conservation	1 / 2	1 / 2	2 / 4								4 / 8
2 Travail et énergie cinétique.	1 / 2	2 / 4	1 / 2								4 / 8
3 Energie potentielle	1	2	~~2~~ 3								4 / 8
4 Chaleur et conservation de l'énergie			1 / 2								1 / 2
5 ELECTR. ET MAGNET. Electrostatique.	2 / 4	3 / 6	2 / 4								7 / 14
6 Charges en mouvement dans des champs électriques.	1	2	3								6 / 12
7 Circuits.	1 / 2	2 / 4	2 / 4								5 / 10
8 Champs magnétiques.	2 / 4	[illegible] / 4	[illegible] / 4								6 / 12
9 Induction électromagnétique.	1 / 2	3 / 6	1 / 2								5 / 10
10 PHYSIQUE MODERNE Atome de Rutherford.		1 / 2	1 / 2								2 / 4
11 Photons et ondes matérielles.	1 / 2	1 / 2	1 / 2								3 / 6
12 Structure atomique système quantique.	1 / 2	1 / 2	1 / 2								3 / 6
TOTAL	12 / 24	19 / 38	19 / 38								50 / 100

RESPONSABLE: Jacques Harvey
coordonnateur ou rédacteur

DATE: 18 Aout 1975

BIBLIOGRAPHY

Alberti, D., Laycock, M., THE CORRELATION OF ACTIVITY-CENTERED SCIENCE AND MATHEMATICS, Haywood, Calif., Activity Resource Company, 1972.

Ausubel, D.P., "General Stages of Intellectual Development", EDUCATIONAL PSYCHOLOGY, A COGNITIVE VIEW, Holt, Rinehart & Winston, 1968.

Davis, J.A., "Lecture Demonstrations are Consistent with Piagetian Theory", THE PHYSICS TEACHER, May 1974.

Duckworth, E., "Piaget Rediscovered", JOURNAL OF RESEARCH IN SCIENCE TEACHING, VOL 2, 1964.

Euller, J., Smith, J., "An Alternative Plan in High School Physics", THE PHYSICS TEACHER, Feb. 1973.

Gillett, M., READINGS IN THE HISTORY OF EDUCATION, Toronto, McGraw-Hill Co., 1969.

Haber-Schaim, U. et al., PSSC PHYSICS, 3rd ED., Lexington, Mass., Heath & Co., 1971.

Haber-Schaim, U. et al., LAB GUIDE, PSSC PHYSICS, 3rd ED., Lexington, Mass., Heath & Co., 1971.

Hobbs, E.D., "Physics Course X-Rayed--A Comparative Analysis of High School Physics Courses in Terms of Basic Assumptions", SCIENCE EDUCATION, 58 (2), 1974.

Holton, G.R., "What is conveyed by Demonstrations", in Meiners, H.F., PHYSICS DEMONSTRATION EXPERIMENTS, VOL. I, New York, The Ronald Press Co., 1970.

IPS Group, Education Development Center Inc., INTRODUCTORY PHYSICAL SCIENCE, Englewood Cliffs, N.J., Prentice Hall, 1967.

Kennedy, K., "Reading Level Determination for Selected Texts", THE SCIENCE TEACHER, March 1974.

Lawson, A.E., Nordland, F., Devito, A., "Piagetian Formal Operational Tasks: A Crossover Study of Learning Effect and Readability", SCIENCE EDUCATION, 58(2), 1974.

McDermott, L.C., "Improving High School Physics Teacher Preparation", THE PHYSICS TEACHER, VOL. 13, No. 9, 1975.

McKinnon, J.W., Renner, J., "Are Colleges Concerned With Intellectual Development", AMERICAN JOURNAL OF PHYSICS, VOL. 39, Sept. 1971.

Moyer, A.E., "Edwin Hall and the Emergence of the Laboratory in Teaching Physics", THE PHYSICS TEACHER, VOL. 14:2, Feb. 1976.

Parent, Monseigneur A., Chairman, REPORT OF THE ROYAL COMMISSION OF INQUIRY INTO EDUCATION IN THE PROVINCE OF QUEBEC, Quebec: The Queen's Printer, 1966, Part Three A.

Piaget, J., "Development and Learning", JOURNAL OF RESEARCH IN SCIENCE TEACHING, VOL. 2, 1964.

O'Connor, J. et al., CHEMISTRY: EXPERIMENTS AND PRINCIPLES, Boston, Mass., Copp-Clark Publishers, 1968.

Renner, J.W., Lawson, A., "Piagetian Theory and Instruction in Physics", THE PHYSICS TEACHER, March 1973.

Renner, J.W., Stafford, D.G., TEACHING SCIENCE IN THE SECONDARY SCHOOL, New York, Harper Row, 1972.

Rutherford, J. et al., THE PROJECT PHYSICS COURSE, New York, Holt Rinehart and Winston, 1970.

Selye, H., STRESS WITHOUT DISTRESS, New York, J.B. Lippincott Co., 1974.

Tyler, R.W., "Research in Science Teaching in a Larger Context", JOURNAL OF RESEARCH IN SCIENCE TEACHING, VOL. II, No. 2, 1974.

Welch, C.A., Supervisor, et al., BIOLOGICAL SCIENCE MOLECULES TO MAN, 3rd ED. Boston, Houghton Mifflin Co., 1973.

Witherspoon, A., THE COLLEGE SURVEY OF ENGLISH LITERATURE, New York, Harcourt, Brace and Co., 1951.