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ABSTRACT

This study sought to evaluate the goals and functions of practical tests designed for students in the natural sciences at the Open University of the Netherlands (OuN). Twelve OuN faculty were asked to rate the importance of 8 general learning objectives, 64 specific learning objectives, and 38 end-terms for undergraduate practicals in the natural sciences. As a result, the faculty were able to devise a new list of general objectives, specific objectives, and end-terms. The faculty showed a clear preference for the achievement of higher academic skills. Three appendixes provide average and normalized ratings of the specific objectives and end-terms, as well as the new classification of general and specific objectives. (Contains 27 references.) (MDM)

Practical objectives at the Open university of the Netherlands

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This research project attempts to build new foundations for the use of practicals, based on their educational, didactic possibilities.

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OTIC Research report 13.2

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Practical objectives at the Open university of the Netherlands

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Abstract

The Open university of the Netherlands (OuN) OuN differs from the more traditional polytechnics and universities along two dimensions. The OuN is an institution for *open, higher distance* education (dimension 1) which offers *interdisciplinary* degree programs in the Natural Sciences (dimension 2). This necessitates a different approach to the curricula in general, and to practicals in particular than that of more traditional institutions of higher learning. To help accomplish this, a list of eight general objectives, 64 specific objectives and 38 end-terms for undergraduate practicals in the Natural Sciences were evaluated by the Faculty of Natural Sciences at the OuN as to their importance to and desirability for inclusion in the degree programs offered. This has led to a prioritizing of the objectives and end-terms and decisions on their inclusion or exclusion in the curricula.

1 Introduction

Although it is quite normal to assume that undergraduate students in the natural sciences will spend a great deal of time working on practicals, this is not the case for students studying at the Open university of the Netherlands (OuN). This is not because the OuN thinks that practicals lack educational value, but rather because it is trying to educate a different type of natural scientist in a different type of educational setting than most other universities. The OuN differs from most other institutions of higher learning along two major dimensions (see figure 1). First, the OuN is an institution for open higher distance education and as such has a student population which differs from the population attending more traditional colleges and universities. For example, almost 70% of the students taking courses in the Natural Sciences are older than 25 years of age, 55% have already received a degree from another institution (i.e. a polytechnic or university) and 70% are employed in a paying position (Joosten & Van Meurs, 1989). Second, the Faculty of Natural Sciences is interdisciplinary in nature and provides Masters level degree programs in the fields of Environmental Sciences, Nutrition and Toxicology, and Planning and Management in the Natural Sciences. This is quite different from regular universities which are primarily monodisciplinary in nature in that they train biologists, chemists, physicists or geologists or any of the sub-specialisations within and between those monodisciplines. The result of these two differences is that the OuN is attempting to educate a different type of student to become a different type of scientist whose skills are different from other types of scientists in that they are primarily cognitive in nature.

	open higher distance education	*regular or traditional university*
monodisciplinary science curriculum	most open universities	most univerity faculties of science
interdisciplinary science curriculum	OuN	a few 'modern' faculties of science

Figure 1
A matrix of institutions of higher education.

These differences make it necessary to re-evaluate the goals, functions, end-terms, and didactics of practicals. This has resulted in a collaborative effort between two departments at the OuN, namely the Faculty of Natural Sciences and the Centre for Educational Technology, to ensure that the little time students are required to spend in a laboratory at the OuN is meaningfully, effectively, and efficiently spent. The goals of this collaboration are:
- The elucidation and enumeration of the problems, premises and objectives of practical work as found in recent literature.
- The selection of those objectives which the Faculty of Natural

Sciences aspires to impart to its students and their inclusion in a pedagogically and didactically well thought out science program.
- A well founded allocation of educational media (printed matter, computer assisted learning and simulation, audiovisual media, tutoring and laboratory work) for maximum effectivity and efficiency.
- Testing and maximization of the allocated media.

This article presents the results of an effort to explicate, categorize and determine the importance of different objectives and end-terms for practicals in the Natural Sciences (based upon previous work by Kirschner & Meester, 1988) for the science curriculum at the OuN. This is the first of three studies on this topic and concentrates on the OuN. The second study (already in progress) focusses on objectives for and end-terms of practicals in the Natural Sciences at traditional universities in the Netherlands (in comparison with the OuN). Finally, a third study will focus on objectives for and end-terms of practicals in the Natural Siences at open universities throughout the world. The results of this third study will of course be compared with the results obtained in the first two studies. This series of studies will hopefully lead to the attainment of the aforementioned second goal.

2 The Background of this Study

Long before the OuN opened its doors to students or produced its first course, a programme working group in the Natural Sciences made fundamental choices relating to the diploma programmes to be offered and the manner in which they would be offered. This group consisted almost completely of natural scientists and educators in the natural sciences. The working group differed radically from the situation sketched by Hurd (1982) for such committees. Hurd characterizes such groups as ad hoc or ad lib 'bull' or 'rap' sessions whereby conflicts of interest and personal bias permeate discussions and where the final report is a minority position which "no one [is] particularly happy with ... and [where] there is little likelihood it will influence educational policy or research". The OuN working group in the natural sciences, lacking both an institutional history and vested interests (both of which usually give rise to conflicts) presented a final report which is still essentially intact after seven years of course development and five years of student enrollment.
This group not only made recommendations for the contents of the diploma programmes and courses, but also placed certain critical notes on the use of programmed undergraduate practicals. They felt that there was a minimum of practical experience necessary within the natural sciences, but for those practicals offered the accent should lie in the acquisition of insight in a scientific way of thinking and on the consequences thereof. The working group also realized that many of the objectives of practicals could also be reached by making use of video, computer assisted instruction, simulations, modelling etc (Kuenen, 1983). We define practicals as a didactic method for the teaching and practicing of those activities relating to experimentation. This begins with the perception of a problem or the

observation of a phenomenon up through the reporting of results in either oral or written form. Hodson (1988) summed this relationship up in the following way. *Experimentation* is a subset of *laboratory bench work* which is a subset of practical work which is a subset of the universe of *teaching/learning methods*.
Having done this, the OuN set about choosing faculty members for the, as of yet 'empty', Faculty of Natural Sciences. The major criterium for selection was not the length of a list of publications nor experience in a laboratory (though those eventually chosen are no less equipped in these areas than their peers at traditional universities), but rather experience in and vision about education in the natural sciences. The faculty members were chosen from all scientific disciplines (physics, biology, chemistry and geology) and together with educational technologists and media technologists set about giving body to the framework devised by the programme working group.
A critical remark must be made at this point. In principle, there are two primary scenarios or variants for the development and production of course materials. The first variant, adopted and in use at the British Open University, is what can be called the *internal variant*. This variant is characterized by a number of large departments and faculties at which courses are produced. All course materials, from conception through production, are produced internally by course teams in the faculties, production departments, television studios, etc. The second variant, currently in use at the OuN, can be called the *recruitment variant*. This variant is characterized by much smaller departments in which small core course teams are responsible for course development and production. The core course teams are composed of a chairperson, who is a content area specialist in the subject on which the course will be made, an educational technologist who is a specialist on the didactics of open higher distance education, a media technologist specialized in the use of electronic media (CAI, (Interactive) Video, audio, etc.), and a publisher. The chairperson then recruits specialists in the subject matter of the course from other universities, industry or government to lend their expertise in the development of the course.

One of the first obstacles which the Faculty of Natural Sciences encountered was the question of exactly how and to what extent students should make use of laboratory practicals. A typical biology programme at a Dutch university requires between 700 and 800 hours of programmed practicals in the first three years of study. For chemistry and physics the number of hours spent in doing practicals is somewhat higher (between 800 and 1000 hours). These figures do not include the non-programmed practicals during the research and/or practical internship parts of the study.
Everyone agreed that practicals were necessary, but everyone also agreed that practicals at the OuN should differ, both in quality (goals, contents, and methods) and quantity from practicals at traditional universities. The problem was that no one knew precisely what this difference should entail. Thus were sown the seeds of this study, which we are now just beginning to reap. The inventory of possible objectives is now complete (Kirschner & Meester, 1988). A paradigm for the use of practicals (Kirschner, 1989) is in development. And finally, this paper, along with the two studies

mentioned in the prior section, signals the beginning of the explicitation and choice of objectives for practicals at the OuN.

3 Objectives for Practicals

Kirschner & Meester give a comprehensive review of learning objectives for and end-terms of practicals in their recent article (1988). Based on a study of more than twenty years of published curriculum research in the Natural Sciences, they defined eight general objectives, two general end-terms, 59 specific objectives for and 38 specific end-terms of undergraduate practicals[1] in the natural sciences, independent of specific scientific disciplines. Though no list is ever exhaustive, it is probably the most complete list to date. The problem is that it is, in all probability neither possible nor desirable to design and develop practicals encompassing all of the objectives needed to reach all of the end-terms present in the list in the short period of time allotted to practicals in an undergraduate study in the Natural Sciences. This problem is compounded in our case by both the limits imposed by open distance education and the choices implied by the decision to develop an interdisciplinary programme. This means that the Faculty of Natural Sciences needed to review the possible objectives, contemplate their importance to a curriculum at the OuN, and then make decisions as to their desirability for inclusion in or exclusion from the programme.

The available literature did not offer very much help. In Swain's review of practical objectives (1974), he came to the conclusion that authors differ on what they think to be desirable practical objectives. There is no major consensus among science educators as to which objectives should be included in practicals.

Kerr (1964) studied the "nature and purpose of practical work in secundary school science teaching". In a survey of science teachers (N=701) he ranked their "opinions" on ten statements referring to practical work from published reports on science teaching methods. This resulted in a ranked list of aims of practical work in science teaching (see Table 1, columns 1 and 2).

Since the publishing of this study in 1964, there have been at least seven other studies published in which approximately the same practical objectives were ranked by teachers as to their importance to the science curriculum (Gunning & Johnstone, 1976; Woolnough, 1976; Ogborn, 1977; Gould, 1978; Boud, Dunn, Kennedy & Thorley, 1980; Beatty & Woolnough, 1982; Lynch & Ndyetabura, 1983).

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[1] A small terminological note may be helpful here. An objective may be defined as that which a student may be expected to attain in an educational setting. An end-term is that which the student may be expected to reach at the end of the study for which practicals are but a means.

Table 1
A comparison of rankings and objectives for practical work in science in six studies.

	Kerr (1964)	Woolnough (1976)	Gould (1978)	Boud (1980)	Beatty[b] (1982)	Lynch (1983)
To encourage accurate observation and careful recording	1	1	1	3	1	6
To elucidate the theoretical work so as to aid comprehension	2	6	8.5	8	8	7
To be an integral part of the process of finding facts by investigation and arriving at principles	3	8	8.5	4	7	3
To promote simple, common-sense, scientific methods of thought	4	3	2	1	3	1
To develop manipulative skills	5	5	6	2	5	5
To verify facts and principles already thaught	6	10	10	O[a]	9	O
To make biological, chemical and physical phenomena more real through actual experience	7	2	3	5	4	2
To give training in problem solving	8	7	4	7	6	O
To fit the requirements of practical examination regulations	9	9	7	O	10	10
To arouse and maintain interest in the subject	10[a]	4	5	9	2	8
n	701	655	214	307	238	257
school type	sixth form	high school	high school	univer-sity	elementary school	univer-sity
subject	all sciences	science	biology	science	science	science

Note:
a) An empty circle means that an objective was not included in that study
b) Beatty studied final year elementary school children!

Indeed Swain's conclusion is correct. Table 1 presents a comparison of the rankings of the ten different objectives in six of the eight studies. The remaining two (Gunning, 1976; Ogborn, 1977) are not included due to the non-comparability of the objectives included in those studies with objectives contained in Kerr (1964).
It is evident that, although there are general trends which can be noted, there is a lack of consensus among the results presented by the researchers as to which objectives are most important and which are least important. A typical example of this lack of agreement is the affective objective 'arousing and maintaining interest in the natural sciences' (objective 10 in Kerr's study). Kerr (in the sixth form), Lynch, Gunning (not included in the table), and Boud, report this objective to be rather unimportant in relation to the other objectives. Ogborn (not included in the table), Beatty, Woolnough, and to a lesser extent Gould report just the opposite. In their research this motivational aim was rather important. Such differences, for example, may be caused by different interpretations of the objective or different schools of thought about how and why practicals should be used. The latter explanation is philosophical or didactic in nature and is not in itself a problem. The former is methodological in nature and may be more problematic. For example, an objective such as 'maintaining interest' might be ranked high by those who consider it a precondition of anything else, and low by those who, while agreeing, thought it to be present in any case.
The exact choice of words (and the interpretation thereof), also is important. An objective such as 'to verify facts and principles already taught' could be interpreted as meaning little more than demonstration or cookbook experimentation, or as devising an experiment to test a hypothesis. Ogborn (1977) studied the ranking objectives and was confronted with simular problems. He came to the following conclusion: "Despite such reservations, which would arise in connection with any such study, the ratings of aims do give some picture of the balance of opinion, and as such bear comparison with the picture of practical work in action" (p. 174).

An objective such as 'to develop manipulative skills' is quite another story. Five of the researchers (Kerr, Woolnough, Gould, Beatty and Lynch) found that this objective was ranked in the center as far as the opinions of teachers were concerned; while one (Boud) found it a highly important objective. Both Gunning and Ogborn, on the other hand, found this objective to be of subordinate importance. These differences are not easily attributable to a possible factor such as changing ideas about the nature, content and didactics of science curricula. Kerr's research, which was carried out in 1962, preceded what has come to be considered a revolution in educational thinking about the didactics of Natural Science education in the United States and Great Britain.
In 1964, the Nuffield Foundation sponsored a project of curriculum development and reform in the Natural Sciences in Great Britain. Their goal was to "foster a critical approach ... with an emphasis on experimentation and enquiry rather than on the mere assimilation of facts". Materials were intended to guide the students through a process of "finding out biological truths", showing students why they should be curious, what kinds of questions they "should investigate", and how students should devise and carry out experiments.

"Experiments are not intended to prove things [students] already know; they are to investigate whether something does or does not happen so that [the student] can form hypotheses which, themselves, can be tested by further experiments" (Nuffield, 1966).
In 1963, the Biological Sciences Curriculum Study (BSCS) Committee and in 1960 the Physical Sciences Study Committee (PSSC) introduced sweeping changes in the different natural sciences curricula in the United States. BSCS was organized to improve biological education at all levels of instruction. It grew from an expressed dissatisfaction of biology teachers with the "tools" with which they "had to work" (Grobman & Mayer, 1968). The teacher wanted to teach modern biology in an imaginative, investigative, and inquiry-oriented fashion, but the texts available fostered the rote memorisation of lists of names, facts, and dates. These themes were "interwoven" with a variety of organisms and levels of organisation (molecule through cells, tissues, organs, individuals, populations, species, communities, and the world biome) to give biology a structure as a science. Recognition of this structure would, according to the BSCS, make a series of patterns that would "tremendously increase the effectiveness of instruction in biology". PSSC, a project begun in 1956 and which produced its first learning materials in 1960, tried to do the same for physics. They attempted to present physics as not merely a body of facts but rather as a "continuing process by which men (*sic*) seek to understand the nature of the physical world" (Haber-Schaim, 1976).
If the changes observed since Kerr's study were attributable to a change in thinking about science curricula, then one would expect to see a persistent increase in emphasis placed on practical work as an aid to developing scientific skills and likewise a de-emphasis of practical work as an aid to understanding and learning theoretical or factual material. Such clear trends are not in evidence in table 1. It is clear then that the results of other researchers, even if we discount the fact that none of them studied the importance of practical objectives in open, higher distance education, show so little concordance that we dare not draw any conclusions from their studies for a curriculum at the OuN. Clearly new research was needed.

4 Purposes of the Study

Kirschner & Meester (1988) distinguished between general instruction objectives and specific behavioural objectives. A third category was the specification of two general end-terms, namely: to obtain good scientific attitudes and to understand the scientific method. The distinction between objective and end-term is as follows. To attain the general and specific objectives, practical work is the goal itself; to attain the end-terms, practical work is one of a number of means to an end.
The research reported upon in this article focusses on the assessment of the importance of general and specific learning objectives for and end-terms of programmed undergraduate practicals in the diploma programmes of the Faculty of Natural Sciences at the OuN. Its goal is the improvement of the current curricula and the setting up of new, didactically better, curricula. We made the conscious and explicit choice of not going the 'theoretical route' to achieve these ends.

Experience has shown that theoretical educational research sec has not very often lead to meaningful and (possibly more important) accepted change in the educational system. Those who must implement the changes (educators, administrators, etc.) are often too far removed from those who 'think up' the changes (educational technologists, educational or curriculum theorists, etc.). Because of this, we have chosen here to assess the desirability and importance of the different objectives and end-terms by taking an inventory of the personal insights, drawn from both experience in science education and insight in the didactics of, in this case open higher distance education, to work towards the achievement of common premises for the development and use of practicals at the OuN. Specifically, the purposes of this study were to rank the general objectives and to classify the specific objectives and end-terms on a scale ranging from indispensable through superfluous so as to be able to make both responsible and implementable choices on their inclusion in or exclusion from the curricula.

5 Method

5.1 *Subjects*

The subjects used were twelve faculty members of the Faculty of Natural Sciences at the Open university of the Netherlands. Three of the subjects were female. All of the subjects had attained at least a Masters Degree in their specific discipline and nine had attained a PhD. The subjects came from the following disciplines: physics, biology, chemistry, earth sciences, biochemistry, toxicology, and pharmacology. All of the subjects had been involved in the development of OuN study materials as course team chairperson and/or as author.

5.2 *Instruments and design*

Two instruments were developed (both in English) to measure the degree of importance of objectives and end-terms for practicals in undergraduate natural sciences.
The first instrument was a pair comparison inventory of the eight general objectives contained in Kirschner & Meester (see table 2). These objectives, along with the order in which they are presented in the table, are based upon the successive steps that a scientist may follow in performing an experiment or doing research.

Pair comparison is a forced-choice method in which the subject is required to choose between two alternatives and is used primarily for the purpose of determining scale values. It is particularly useful when (some of) the items to be scaled may be presumed to be close to each other on the dimension to be scaled. Other methods of ranking might then lead to arbitrary results. The essence of pair comparison is that sets of pairs of stimuli or items are presented to the subject with instructions to choose one member of each pair on the basis of a stated criterion (Kerlinger, 1973). In this study the criterion was the desirability of the general objective as part of the undergraduate curriculum. The eight objectives were combined in all possible pairings.

Table 2
General objectives used in the pair comparison
(from Kirschner & Meester, 1988)

a To formulate hypotheses
b To solve problems
c To use knowledge and skills in unfamiliar situations
d To design (simple) experiments to test hypothesis
e To use laboratory skills in performing (simple) experiments
f To interpret experimental data
g To clearly describe the experiment
h To remember the central idea of an experiment over a significantly long period of time

There were 28 pairs for the eight stimuli. The sequence of pairs was arranged so that each objective was equally present as first member of the pair as it was as second member. It was not possible to achieve that one objective was not given in two consecutive pairs, but the objectives were for the most part as far apart as possible (Guilford, 1954). The pairs were presented in a small booklet, one pair per page. In an attempt to compensate for question-order artefacts, subjects were instructed to first read or skim through the whole booklet to acquaint themselves with all 28 pairs of objectives and only then to begin the booklet again, this time making choices within each pair of objectives without referring to or changing earlier decisions.
The second instrument was a Likert-scale objectives inventory containing 102 items which were analogs of the 97 specific objectives and end-terms presented in Kirschner & Meester (1988). The 97 objectives and end-terms were screened by a number of educational technologists and educators in the Natural Sciences with respect to ambiguity, clarity and multi-interpretability. Based upon this screening, five of the items were dropped, many were rewritten so as to be less ambiguous and eight were split up into multiple objectives, so that we eventually ended up with aninventory of 102 items. Of these 102 items, 64 were specific objectives and 38 were end-terms. The 102 items were then rearranged in a random fashion. The subjects were asked to assess the importance of each individual objective or end-term for practicals in a Natural Science curriculum at he OuN on a five-point scale. The five ratings and their corresponding definitions were:

indispensable	This objective is essential and must be included in the programme; much emphasis should be placed on this objective
important	This objective should be included, but not necessarily emphasized
neutral	I don't have an opinion as to this objective; by a vote on such an objective I would abstain
not really necessary	This objective is of minimal importance; if there is lack of time or opportunity then this objective need not to be included
superfluous	This objective should not be included in the curriculum; no time need be reserved for this objective

Again here the subjects were instructed to read or skim through the whole inventory to acquaint themselves with all of the objectives and only then to rate each objective's importance separately without referring to or changing earlier responses.

5.3 *Validity and reliability*

A test or scale is valid (or invalid) for the scientific or practical purpose of its users and not valid (or invalid) in a vacuum. The inventories developed here are *neither* meant for prediction *nor* for the testing of hypothesized relations or theoretical constructs. Criterion-related validity and construct validity respectively are therefore not of consequence here. What is of consequence is the representativeness of sampling adequacy of the content of a measuring instrument. Content validation is guided by the question: "Is the substance or content of this measure representative of the content or the universe of content of the property being measured" (Kerlinger, 1973). Seeing as how the inventories are based upon the most complete set of objectives collected to date (Kirschner & Meester, 1988), the answer to this question is an unequivocal yes.

Reliability of the total inventory of 102 items (Cronbach's alpha) was .95. The Guttman split-half coëfficient was .93. Since the inventory was composed of both objectives and end-terms, it was decided to split the inventory into two subscales and calculate the reliability of each of the subscales separately. The objectives subscale had a reliability (Cronbach's alpha) of .93. The end-term subscale had a reliability (Cronbach's alpha) of .86.

6 Results

6.1 *General objectives*

In order to estimate to what extent the faculty members agree among themselves about the value of the different objectives the Kendall coëfficient of concordance (*W*) was used (Kendall, 1955). This is a measure of the relation among *several* rankings of *N* objects or individuals. It is especially useful in studies of interjudge reliability and has applications in studies of clusters of variables (Siegel, 1956). The coëfficient of concordance, *W*, is defined as the following ratio:

$$W = \frac{S}{S_{max}} = \frac{12S}{m^2 (n^3 - n)}$$

where m = the number of faculty members
n = the number of objectives
S_{max} = the sum of the squares of the differences between observed and expected rank totals
S = the sum of the squares of the actual deviations in the rank totals

Kendall's *W* expresses the degree of association among variables and can vary from zero, representing no agreement, to 1.0, representing perfect agreement.

The coëfficient of concordance was .46, which is significant at better than the 1% level of probability ($W = 0.4632$, $X^2_- = 38.91$, $p < .001$). This means that the subjects showed a large degree of agreement on the ranking of the objectives and that the judges (subjects) are applying essentially the same standard in ranking the N objectives under study. Finally, the number of circular triads (a measure of inconsistency in the answer patterns : A > B > C > A) was small. Where necessary, corrections for these triads were made. To gain insight into the evaluation of the general objectives by the subjects we tallied how often each general objective was preferred in the pair comparisons. In this way it is possible to achieve a first impression of the priorities. The results of the tally can be seen in figure 2.

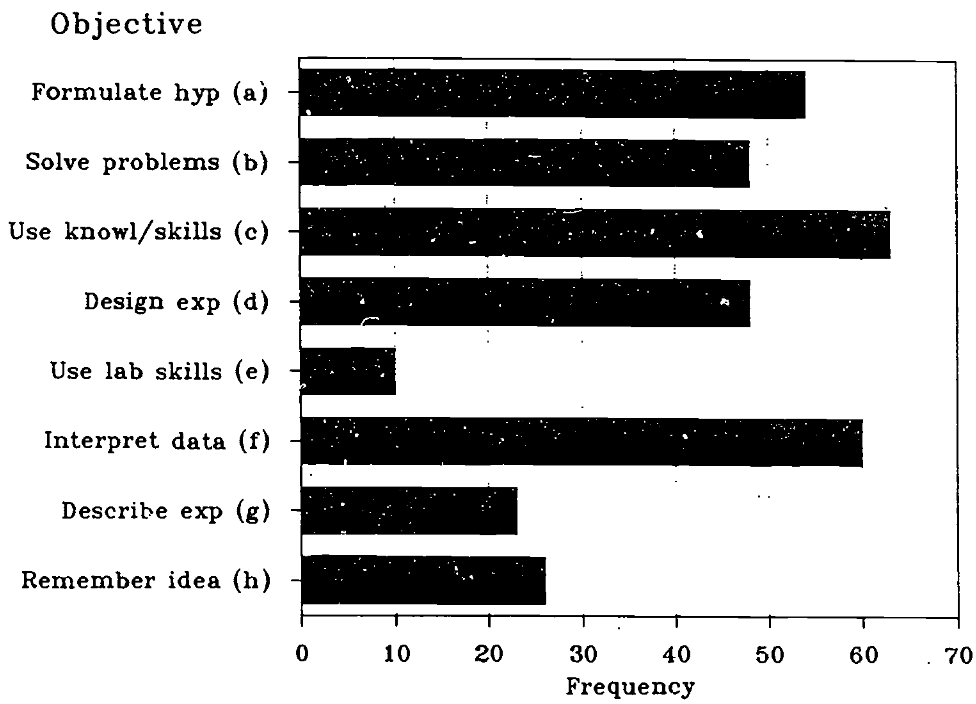

Figure 2
Frequencies of the preferences of the general objectives from the pair comparison inventory. The maximum is 84.

The list of objectives, rearranged according to their rankings along with the average score attributed to the objectives by the faculty members, is shown in table 3.

Table 3
General objectives ranked in descending order of importance.

Rank	*Average score*[a]	*Objective*
1	5.25	To use knowledge and skills in unfamiliar situations (c)[b]
2	5.00	To interpret experimental data (f)
3	4.50	To formulate hypotheses (a)
4	4.00[c]	To design (simple) experiments to test hypotheses (d)
5	4.00[c]	To solve problems (b)
6	2.17	To remember the central idea of an experiment over a significantly long periode of time (h)
7	1.92	To clearly describe the experiment (g)
8	0.83	To use laboratory skills in performing (simple) experiments (e)

[a] The average score is the sum of the positive responses to a certain objective in the pair comparison inventory divided by the number of subjects.
[b] The letters in parentheses correspond with the letters in Table 1.
[c] Although the average score of these two general objectives is the same, a scale separation matrix of normalized (Z) scores showed a slight difference in preference.

Table 4 presents an overview of the significance levels of a paired samples *t*-test of the differences between the weightings of the general objectives. There appears to be a concrete cut-off-point between the five highest ranked objectives (up to and including 'To solve problems') and the three lowest ranked objectives.

Table 4
Significance levels of a paired samples t-test of the difference between the weightings of the general objectives.

	General objective							
General objective	*(c)*	*(f)*	*(a)*	*(d)*	*(b)*	*(h)*	*(g)*	*(e)*
Use knowledge/skills (c)	---	.742	.389	.183	.049	.002	.000	.000
Interpret exp data (f)		---	.455	.146	.332	.000	.000	.000
Formulate hypotheses (a)			---	.477	.615	.012	.001	.001
Design exp to test (d)				---	1.000	.025	.007	.000
Solve problems (b)					---	.078	.023	.002
Remember central idea (h)						---	.667	.058
Clearly describe exp (g)							---	.059
Use lab skills (e)								---

6.2 *Specific Objectives*

The objectives inventory which contained both the specific objectives and the end-terms was split into its component parts so as to allow for the analysis of the specific objectives and the end-terms separately.

A quick look at the average ratings of the 64 specific objectives[2] leads to the conclusion that the number of objectives considered to be important (indispensable or important) far outnumbers those considered to be unimportant (not really necessary or superfluous). This is highly evident if one divides the scale into five equal ranges and compares the number of objectives falling into each range (see figure 3).

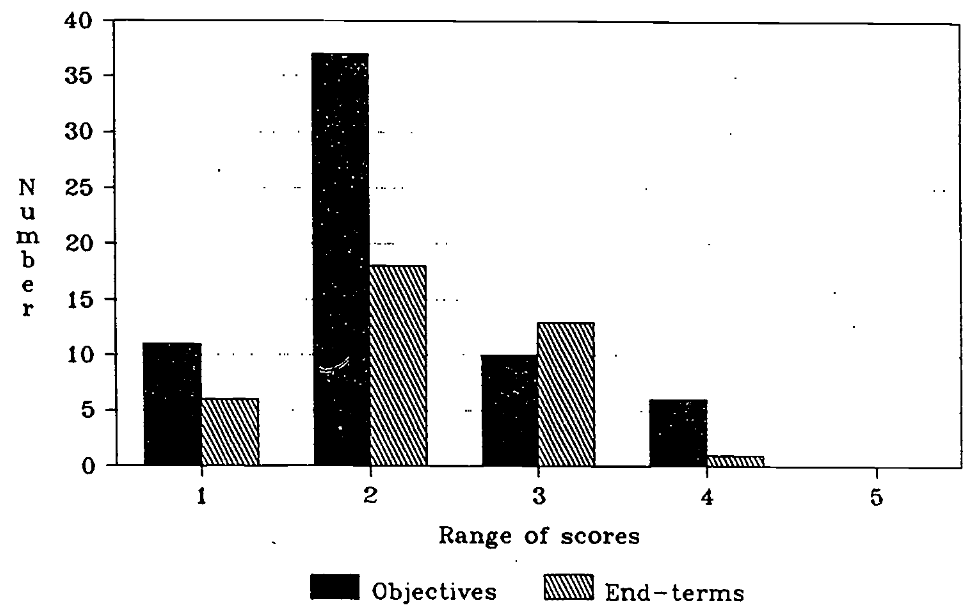

Figure 3

Number of objectives and end-terms falling into the five ranges of importance.

Range 1 (m = 1.00 - 1.79) is indispensable; range 2 (m = 1.80 - 2.59) is important; range 3 (m = 2.60 - 3.39) is neutral; range 4 (m = 3.40 - 4.19) is not really necessary; range 5 (m = 4.20 - 5.00) is superfluous.

The results of the inventory make it clear (see appendix I) that the subjects place a great emphasis on what may be called the acquisition of academic skills. These skills may be defined as "learned skills which manage (the student's) own learning, remembering and thinking ... certain techniques of thinking, ways of analyzing problems, (and)

[2] The average ratings (m) and accompanying Z-scores for the specific objectives can be found in Appendix I.

approaches to the solving of problems." (Gagné, 1977).
Of the eleven most highly rated specific objectives ($1.0< m <1.8$, $Z >.85$) six are specifications of the general objective 'to interpretexperimental data 'which was ranked second by the subjects. Those specific objectives are: *to interpret the reliability and meaning of results, to assess the relevance of experimental data with regard to hypotheses, to apply elementary notions of statistics, to evaluate differences between expected and actual results, to relate experimental outcomes to a particular theory,* and *to make order-of-magnitude calculations and estimates* (see appendix I).

By these same eleven objectives are also three specifications of another highly ranked global objective 'to solve problems', namely: *to decompose large problems into smaller ones, to understand what is to be measured in an experiment,* and *to understand the purpose of an experiment.*
The last two of the eleven 'indispensable' specific objectives: *to derive testable hypotheses from theories* and *to describe central aspects of an experiment* are specifications of the general objectives 'to formulate hypotheses' and 'to clearly describe the experiment' respectively. Of these only the latter is not one of the five most important general objectives.
A noteworthy anomaly, which we shall return to in the discussion section, is the fairly high regard for the specific objectives pertaining to describing an experiment. General objective (g) 'to clearly describe the experiment' was ranked next to last in importance by the subjects. The specifications of this general objective: *to describe the central aspects of an experiment (see above), to communicate experimental findings in written and oral form* and *to summarize an experiment based on results* are, however, all ranked above the average of all the specific objectives ($m < 2.29$, $Z > 0.00$).
On the other end of the spectrum, it should be noted that all five of the lowest rated specific objectives ($3.4 < m < 4.19$, $Z <-1.57$) pertain to simple manual and or recording skills. These skills are: *to calibrate instruments, to develop measurement techniques, to set up lab equipment quickly and correctly, to handle modern equipment, and to manipulate apparati.* Again there is agreement between the racing of the specific objectives and the ranking of the general objectives. If one uses the same Z-scores as cut-off point for the lowest rated objectives ($Z <-.85$), then this list of five simple manual and recording skills are expanded with four new lower order objectives *(collect experimental data; use practical laboratory skills; put basic laboratory techniques to use; know and apply alternative measurement techniques)* plus two 'cookbook' skills *(confirm already known facts and laws; confirm principles and theories discussed in lectures or books).*

6.3 *Specific end-terms*

A similar pattern can be seen with respect to the average ratings of the 38 end-terms[3]. These end-terms are specifications of the two general end-terms in Kirschner & Meester (1988), namely:

I To obtain good scientific attitudes, and
II To understand the scientific method

As was the case with the specific objectives, the curve is skewed left with the number of end-terms considered to be important far outnumbering the end-terms which are considered to by unimportant (see figure 3).

Again here, the end-terms which relate to academic skills are clearly the most important. The six highest ranking end-terms ($1.0 < m < 1.79$, $Z > 1.0$) all deal with some aspect of critical academic or mental skills *(solve problems in a critical, academic way; approach observed phenomena from a scientific point of view; make decisions while solving problems; have a critical attitude to experimental results; survey literature relevant to a problem; interpret data in literature)*.

Of the five end-terms rated as being least important ($Z < 1.0$) three have to do with either an aesthetic/romantic view of science practicals *(experience the joys and sorrows...)* and two with a possibly unrealistic or highly idealistic view of undergraduate practicals *(work in research and development laboratories; use motor skills inherent to professionals)*.

7 Discussion

7.1 *General objectives*

If one procedes from the premise that the faculty of Natural Sciences at an institution as the Open university of the Netherlands should educate it's students to become critical, academic thinkers, then it is not surprising that the five most highly regarded general objectives are also those which deal with these strivings. It is also not surprising that faculty members of such an institution would rank an objective such as 'to use laboratory skills in performing (simple) experiments' last. What is surprising is the low ranking of the objectives 'to remember the central idea of an experiment over a significantly long period of time' and 'to clearly describe the experiment'.

The low score for the former can possibly be attributed to the verb *to remember*. The subjects have all, at one time or another, been integrally involved in or responsible for the development of learning materials (courses in the Natural Sciences) at the OuN. As such, they are well versed in the explicitation of concrete, specific objectives and are thus also well acquainted with taxonomies of learning objectives and the rules for formulating them (Bloom, Engelhart,

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[3] The average ratings (m) and accompanying Z-scores for the specific objectives can be found in Appendix II.

Furst, Hill & Krathwohl, 1956; Gronlund, 1970). Noteworthy in this respect is the 'low' ranking for the cognitive category *knowledge*. Bloom e.a. (1956) defines knowledge as "the remembering of previously learned material" and says further that "knowledge represents the lowest level of learning outcomes in the cognitive domain". In this light, it is not at all strange that the general objective 'to remember the central idea of an experiment over a significantly long period of time' was not deemed to be of great importance.
Stranger is the low ranking of objective (g) 'to clearly describe the experiment'. In 1987, the Faculty of Natural Sciences produced a report defining the programs and courses to be developed. They also defined the general end-terms for those studying in the Natural Sciences at the OuN and included in those end-terms that graduates should be able to write reports and make oral presentations of scientific findings. The low ranking is even more remarkable in light of the fairly high ratings of the specific objectives ascribed to this general objective (see the Results section and Appendix I). Just as was the case with the previous general objective, the low ranking here may be attributed to the way in which the subjects interpreted the word *describe*. To describe, according to Gronlund (1970), is one of the illustrative behavioral terms for stating specific learning outcomes of knowledge objectives. This interpretation was later confirmed in discussions with the subjects. When confronted with the general objective, it is possible that the subjects interpreted *to describe* in such a manner, while when rating the specific objectives they were clearly aware of the necessity of communicating findings in written and oral forms, summarizing and discussing results and describing central aspects of an experiment. Description is, as interpreted by Kirschner and Meester (1988), if anything, a higher order cognitive objective belonging to the synthesis category in Bloom et al's (1956) taxonomy. Description, as such, is "putting parts together to form a new whole... (involving)the production of a unique communication. Learning outcomes in this area stress creative behaviors, with major emphasis on the formulation of *new* patterns or structures" (Gronlund, 1970).
Leopold Klopfers 'Table of specifications for science education' (1971) sheds some light on the rankings of the general objectives in this study. Within the cognitive domain, Klopfer identifies six categories of behavior, increasing in complexity. They are:

1. Knowledge and comprehension
2. Processes of scientific inquiry I: Observing and measuring (with description as a student behavior herein)
3. Processes of scientific inquiry II: Seeing a problem and seeking ways to solve it
4. Processes of scientific inquiry III: Interpreting data and formulating generalizations
5. Processes of scientific inquiry IV: Building, testing and revising a theoretical model
6. Application of scientific knowledge and methods

Along with these six cognitive categories, Klopfer distinguishes one motor category and two attitude categories, namely: manual skills, attitudes and interests, and orientation.

If we place our general objectives and end-terms next to Klopfer's categories, we see a remarkable agreement. If one assumes that the subjects ranked the objectives based upon a preference for academic and thus higher order behaviors, then we arrive at the following table.

Table 5
Correspondence between the rankings of the subjects and complexity according to Klopfer (1971).

General objective	*Rank*	*Klopfer's category*	*Rank*
to clearly describe experiments (g)	7	Processes of scientific inquiry I	II
to remember the central idea of an experiment (h)	6	Knowledge and comprehension	I
to solve problems (b)	5	Processes of scientific inquiry II	III
to design (simple) experiments to test hypotheses (d)	4	Processes of scientific inquiry IV	V
to formulate hypotheses (a)	3	Processes of scientific inquiry IV	V
to interpret experimental data (f)	2	Processes of scientific inquiry III	IV
to use knowledge and skills in unfamiliar situations (c)	1	Application of scientific knowledge and methods	VI

Notes: The general objectives are ordered from the least preferred (7) to most preferred (1).
Klopfer's categories are ranked from least complex (I) to most complex (VI).
The general objective (c) 'to use laboratory skills in performing (simple) experiments' has been omitted because it does not belong to the cognitive domain. Thus, there are only seven objectives

Klopfer's three other categories show a distinct resemblance to the last general objective and the two general end-terms:

- 'to use laboratory skills in performing (simple) experiments' corresponds with Klopfer's category 'Manual skills' which encompasses the development and performance of laboratory skills with care and safety,
- 'to obtain good scientific attitudes' corresponds with Klopfer's category 'Attitudes and interest', and
- 'to understand the scientific method' corresponds with Klopfer's 'Orientation', encompassing the development of a multi-facetted orientation (relationships, philosophical limitations historical perspectives, and moral and social implications) towards science.

7.2 *Specific objectives*

As stated earlier, the ratings of the specific objectives concur fairly well with the rankings of the general objectives. Within the 'top twenty' specific objectives, there are but three which were not classified as specification of the 'top five' general objectives as classified by Kirschner and Meester (1988). This pattern is also visible at the bottom end of the ratings.

There are, however, a few objectives such as *to confirm already known facts and laws* and *to confirm facts, principles and theory from lecturers or books* which are specifications of the second most highly rated general objectives (to interpret experimental data) but are rated here near the bottom. This again may be due to the verb *confirm* which implies a 'cookbook' approach to the use of practicals and as such undesirable in a modern science curriculum.

The anomaly between the general objective 'to clearly describe the experiment' and its specific contents was already discussed in the previous section.

7.3 *Specific end-terms*

It was to be expected that most of the end-terms would fall into the ranges 'indispensable' and 'important'. The general and specific end-terms are endemic to all science curricula irrespective of the type (open, higher distance or traditional) or nature (interdisciplinary or monodisciplinary) of the curriculum or scientific discipline. As stated in the results section, the end-terms rated as being least important were those which either overly romantic or unrealistic for undergraduate practicals.

8 Conclusions and Implications

It is possible to rate objectives according to the preferences and to use these ratings to eventually make choices as to the inclusion of different objectives in a curriculum. The Faculty of Natural Sciences at the OuN shows a clear preference for the achievement of 'higher academic skills'. Evaluation of the results has lead to a restructuring of the general objectives and their concommitant specific objectives such that there remains six general objectives and 38 specific objectives.
Based upon a combination of a criterion average (*m*) and the rating of the general objective to which each specific objective belongs, the 64 specific objectives were reduced in number to 38. As is to be expected, most of the objectives which were dropped dealt with the achievement of simple manual or recording skills or with the achievement of 'cookbook' objectives. When these 38 specific objectives were assigned to the eight general objectives, one general objective (*h*: to remember the central idea of an experiment over a significantly long period of time) was empty and one general objective (*a*: to formulate hypotheses) contained only one specific objective which could just as easily be assigned to objective *b* (to solve problems). These two were thus eliminated. Objective *e* (to use laboratory skills in performing experiments) was kept, but in a trimmed down form. Finally objective g (to clearly describe the experiment) was, although rated rather low by the subjects, kept due to the high ratings of its specific objectives.
This yields the following list of general objectives:
- To solve problems
- To use knowledge and skills in unfamiliar situations
- To design (simple) experiments to test hypotheses
- To use laboratory skills in performing (simple) experiments
- To interpret experimental data
- To clearly describe the experiment

Appendix III contains a list of the general and specific objectives chosen on the basis of this study. Since the amount of time and money that can be spent on practicals is not limitless, this preference must be echoed in the curriculum, at a cost to lower level manual skills dealing with the use of laboratory skills. Practicals at the OuN will be realigned tc coincide with these results. At the moment the OuN is developing an upper level (junior/senior) "Experimentation" course which will take the place of smaller monodisciplinary science labs and which will be a prerequisite for entrance to an internship for the achieving of a Master's degree. This course will attempt to shift the emphasis in the use of practicals away from the traditional workbench approach prevalent in most universities towards an integrated laboratory. This shift will be based upon a paradigm for the implementation of practicals for the achievement of academic skills in Kirschner (1988). skills, The contours of this new course are rapidly becoming rapidly visible. It is being designed primarily for the achievement of those objectives (primarily academic in nature) which a student needs to master either before entering or after leaving the laboratory. Manipulative laboratory skills are definitely taking a back seat here. Practical forms such as "experimental seminars" and "simulations" outside of the laboratory will take the lion's share of the work. "Wet laboratories" or workbench activities will play a secondary role in the course. After development of this upper level course, a lower level (freshman/sophomore) experimentation course will probably be developed to take the place of the present biology, chemistry and physics labs. Both of these courses wil be based, both in content as in didactics, on the ratings of the objectives reported here.

Finally, it will be interesting to compare the ratings obtained in this study with those obtained from traditional, monodisciplinary Natural Science faculties. The same instruments used in the present experiment have already been mailed out and a high percentage of responses (70%) has been received. The analyses have already begun. A follow up article will hopefully answer the question as to whether the dimensions discussed in the introduction actually make a difference in the type of objectives to the pursued in higher science education.

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Appendix I Averages and normalized scores of the specific objectives

The characters preceding the objectives correspond with the general objectives.

		m	Z
f	Interpret reliability and meaning of results	1.25	1.64
f	Assess relevance of exp. data with regard to hypothesis	1.5	1.24
f	Apply elementary notions of statistics	1.5	1.24
a	Derive testable hypotheses from theories	1.67	0.98
g	Describe central aspects of an experiment	1.67	0.98
f	Relate exp. outcomes to a particular theory	1.67	0.98
f	Evaluate diff. expected & actual results	1.67	0.98
b	Decompose large to smaller problems	1.67	0.98
b	Understand what is to be measured in an exp.	1.67	0.98
f	Make order-of-magnitude calculations and estimates	1.75	0.85
b	Understand the purpose of an experiment	1.75	0.85
d	Recogn. hazards so as to take safety precautions	1.83	0.73
f	Evaluate exp. outcome with respect to a hypothesis	1.83	0.73
c	Apply known principles to new situations	1.83	0.73
f	Analyze exp. data to draw conclusions	1.83	0.73
c	React adequately to unforeseen results	1.83	0.73
e	Observe phenomena in a qualitative way	1.83	0.73
h	Present essentials of an exp. in written form	1.83	0.73
d	Design subsequent exp. involving phenomena	1.92	0.58
f	Incorporate unexpected exp. results in new model	1.92	0.58
g	Communicate exp. findings in written form	1.92	0.58
e	Be flexible in modifying exp.	1.92	0.58
b	Derive & evaluate relationships	1.92	0.58
c	Recognize & define scientific problems	2	0.46
f	Use obtained data to make estimates in new situations	2	0.46
b	Use exp. data to solve specific problems	2	0.46
b	Solve problems in a multi-solution situation	2	0.46
d	Properly plan an experiment	2	0.46
d	Design an exp. to verify a theory/hypothesis	2	0.46
f	Estimate outcome of exp. meas. within given precision	2	0.46
c	Apply current knowledge in solving new problems	2	0.46
f	Evaluate contribution direct to derived errors	2.08	0.33
g	Summarize an exp. based on results	2.08	0.33
d	Understand scope & limits of exp. techniques used	2.08	0.33
g	Communicate exp. findings in oral form	2.08	0.33
e	Handle waste safely	2.17	0.19
c	Construct models based on exp. findings	2.17	0.19
e	Observe phenomena in a quantitative way	2.17	0.19
g	Suggest follow-up investigations	2.25	0.07
e	Conduct experiments safely	2.25	0.07
f	Apply principles instead of rote formulae	2.33	-0.06
e	Keep a day-to-day lab diary	2.33	-0.06
c	Construct models which fit exp. evidence	2.33	-0.06
b	Understand measurement of diff. phenomena	2.42	-0.2
g	Discuss results with other scientists	2.42	-0.2
f	Process experimental data	2.5	-0.33
d	Design relevant observation techniques	2.5	-0.33
e	Understand lab instructions	2.58	-0.45

		m	Z
b	Solve difficult scientific problems	2.67	-0.59
b	Identify variables & determine emp. relations	2.67	-0.59
e	Carry out accurate measurements	2.75	-0.72
e	Collect experimental data	2.83	-0.85
e	Use practical (as opposed to theoretical) lab skills	2.92	-0.99
f	Confirm facts, princ. & theory from lect./books	3	-1.11
e	Put basic lab. techniques to use	3.08	-1.24
a	Translate conc. def. into set of meas. procedures	3.08	-1.24
e	Follow instructions	3.17	-1.38
e	Know & apply altern. meas. techniques	3.25	-1.51
f	Confirm already known facts and laws	3.42	-1.77
e	Manipulate apparati	3.5	-1.9
e	Handle modern equipment	3.58	-2.03
e	Set up lab equipment quickly & correctly	3.67	-2.17
d	Develop measurement techniques	4	-2.69

Appendix II Averages and normalized scores of the specific end-terms

The roman numerals preceding the end-terms correspond with the general end-terms in this article.

		m	*Z*
II	Solve problems in a critical, academic way	1.17	2.16
II	Approach observed phenomena from a scient. point of view	1.33	1.88
I	Make decisions in proper course of action of prob-solving	1.5	1.59
I	Have a critical attitude to exp. results	1.5	1.59
I	Survey literature relevant to some problem	1.5	1.59
I	Interpret data in literature	1.75	1.15
I	Formulate a problem that can be researched	1.83	1.01
I	Approach a problem with an open mind	1.92	0.86
I	Form attitudes related to value & uses of exp. science	2	0.72
II	Deeply understand the discipline studied	2	0.72
I	Discover limitations of a theory/model	2	0.72
I	Act independently & take initiative	2.08	0.58
I	Apply one's insights, discoveries & conclusions	2.25	0.29
I	Plan ahead	2.33	0.15
II	Be interested in the subject area	2.33	0.15
I	Work in groups to solve scient. problems	2.42	-0.01
II	Appreciate relationship between nature & science	2.42	-0.01
II	Design new exp. in their own fields	2.42	-0.01
II	Experience challenge of exp. method	2.5	-0.15
I	Be self-confident and independent	2.5	-0.15
I	Take active part in the process of science	2.5	-0.15
I	Work independently of others	2.58	-0.29
II	Experience spirit & essence of scient. inquiry	2.58	-0.29
II	Build framework for facts, princ & theory from lect/books	2.58	-0.29
II	Use the lab as an instrument for discovery	2.67	-0.44
I	Appreciate the usual & unusual	2.67	-0.44
II	Determine limits under which a theory applies	2.67	-0.44
I	Concretize theoretical notions	2.75	-0.58
II	Do experiments	2.83	-0.72
II	Illustrate facts, princ. & theory of lectures/books	2.83	-0.72
I	Use mental skills inherent to professionals	2.83	-0.72
II	Intuitively understand scientific phenomena	2.92	-0.88
I	Tackle a problem without help of others	2.92	-0.88
II	Experience kinship with the scientist	3.25	-1.45
II	Experience past and present scientists' joy	3.25	-1.45
I	Use motor skills inherent to professionals	3.33	-1.59
II	Experience joys & sorrows of experimenting	3.33	-1.59
II	Work in research & development labs	3.5	-1.88

Appendix III New classification of general and specific objectives

A. To solve problems

- solve difficult scientific problems by decomposing them into smaller problems
- solve problems in which there is more than one usable solution strategy
- derive and evaluate relationships between observed scientific phenomena
- use experimental data to solve specific problems
- understand the purpose of an experiment
- understand what is to be measured during an experiment
- identify the variables that adequately describe some system's state and empirically determine the way they are related
- derive testable hypotheses from theories

B. To use knowledge and skills in unfamiliair situations

- apply known principles and knowledge in solving new problems
- recognize and define scientific problems
- construct models based on experimental findings
- react adequately when confronted with unforeseen results

C. To design (simple) experiments to test hypotheses

- design an experiment to test a theory or hypothesis
- properly plan an experiment
- design observation techniques relevant to the task at hand
- design subsequent experiments involving the phenomena being studied
- recognize hazards so as to take appropriate safety precautions
- understand the scope and limiting conditions of the experimental techniques used

D. To use laboratory skills in performing (simple) experiments

- understand laboratory instructions
- experiment safely
- observe phenomena in a qualitative way
- observe phenomena in a quantitative way
- be flexible with respect to modifying experiments in light of results obtained in prior experimentation
- keep a day-to-day laboratory diary in such a way that a third person can repeat the experiments

E. To interpret experimental data

- process experimental data
- analyse experimental data in order to draw conclusions from them
- apply principles rather than rote use of computational formulae in the theoretical analysis of the lab experiment
- apply elementary notions of statistics (e.g. random errors, systematic errors, mean values, uncertainty and confidence limits) in evaluating experimental data
- evaluate how errors in direct measurements may contribute to errors in a derived measure
- evaluate the experimental data with regard to the hypothesis or theory being tested
- make order-of-magnitude calculations and estimates within given precision
- incorporate unexpected experimental results in a new model
- use data already obtained to make estimates regarding not yet tested situations
- interpret the reliability and meaning of results gained through experimentation (either their own or those of others)

F. To clearly describe the experiment

- give a written description of the essentials of an experiment based on collected data
- communicate experimental findings in oral form
- suggest follow-up investigations once the results of a scientific investigation are known
- discuss results of scientific investigations with other scientists

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