Recruiting Female Students to Higher Education in Mathematics, Physics and Technology

An Evaluation of a Swedish Initiative

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HÖGSKOLEVERKET
National Agency for Higher Education

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Högskoleverket 1998

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Recruiting Female Students to Higher Education in Mathematics, Physics and Technology. An Evaluation of a Swedish Initiative
Produced by the National Agency for Higher Education (Högskoleverket), Stockholm, February 1998
Högskoleverket Studies 1998:3 S (Högskoleverkets skriftserie)
ISSN 1400-9498
ISRN HSV-SS—98/3—SE
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Graphic Design: Information Department
Printed by Printgraf, Stockholm, Sweden, February 1998

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Preface

This report presents the results of an evaluation of a Swedish government initiative aimed at recruiting female students to higher education in mathematics, science, and technology by promoting change in the form and content of study programmes previously dominated by men. Five development projects received funding within the initiative: Reforming the Computer Science and Engineering Programme (D++), at Chalmers University of Technology, Scientific Problem Solving at Göteborg University, Women in Engineering Education at the University of Karlstad, The IT-Programme at Linköping University, and the Project Programme at Stockholm University, all of them providing degree programmes which address the needs of new groups of students by offering courses which take into account a wide range of student abilities, such as communicative skills, problem-solving capacities and abilities to view the subject matter from different disciplinary perspectives.

The evaluation was carried out from September 1995 to December 1997, a period which coincided with the implementation period of the programmes. This means that the evaluation does not render a conclusive view of the outcomes of the initiative, but rather offers a picture of trends. The aim of the evaluation is to open a dialogue on the possibility of attracting new groups of students to science and technology programmes by designing them in ways which are believed to meet these students' demands.

Both quantitative and qualitative methods of gathering and analysing data are used in the evaluation. Following the introduction to the study an overview is offered, which renders a statistical picture of the recruitment trends and points to some problematic aspects of the developmental projects. These aspects are further developed in four case-studies which provide in-depth descriptions of how students within three of the projects approach learning tasks presented to them in teaching. Two of these case-studies have been commented on in interviews with teachers involved in the developmental projects and with commentators who are not directly involved in the projects but who take an interest in the programme policies. In the discussions about the outcomes of the initiative, data from these interviews are used to open a dialogue on the merits and shortcomings of the forms of work implemented within the projects as ways to make studying meaningful and engaging to students whose experiences and attitudes may differ from what is traditionally expected of entrants to science or technology programmes.

Many people have contributed to this study and I want to thank them all for their willingness to participate in the evaluation. I have thought it prudent not to identify the individual students, teachers and commentators who contributed to various parts of the evaluation, but to all of those who allowed us to document and describe their work and to share their views I want to express my deepest gratitude. First of all I would like to thank the 65 students who volunteered to take part in the case-studies and who have contributed, not only by letting us gather in-depth information about their ways of learning, but also by communicating their experience of studying within the programmes in the most generous and straightforward way. I would also like to express my thanks to the teachers and commentators for their close readings of the narratives presented in this report and for their critical and reflective comments on the descriptive accounts of the situations in which learning takes place. I would also like to thank the administrators at the universities in Göteborg, Karlstad, Linköping and Stockholm and at Chalmers University of Technology for their professional help in furnishing me with the data needed for the overview of all the 604 students enrolled in the programmes during the period covered by this evaluation. I have learnt that administrative routines are not always suited to the needs of alternative study programmes, especially not to programmes which may conflict with the traditional disciplinary structures by introducing interdisciplinary project studies or problem-based learning.

I am also grateful to a number of my colleagues and friends who have helped me during the research process. Gudrun Brattström, Senior Lecturer at the Department of Mathematics, Stockholm University, has co-operated with me in conducting the overview. Much of what appears in the quantitative part of the evaluation reflects understandings which Gudrun and I arrived at together. Parts of the evaluation have been co-ordinated with a research project financed by the Swedish Council for Planning and Co-ordination of Research (FRN): *Ways of learning mathematics in gender-inclusive higher education*, a project conducted by a research group which, apart from Gudrun Brattström and myself, also includes Mats Martinsson, Lecturer at

the Department of Mathematics, Chalmers University of Technology and Göteborg University. Two of the case-studies presented in the qualitative part of this evaluation are partly carried out within this project and with financial support from the FRN: Gudrun and Mats have been my co-researchers in gathering and analysing the data used in the chapters about Learning Mathematics in a Collaborative Setting and of Mathematical Problem Solving in Computer Science and Engineering. I want to thank them both for all the stimulating discussions we have had. Max Scheja and Cecilia Lundholm, two of my research students, have carried out most of the student interviews presented in the chapter on Student Views of the Forms of Work, and they have also contributed to numerous discussions of the issues addressed in this evaluation within the research seminar for *Learning and Communication* at the Department of Education, Stockholm University. I also want to thank Tom Lavelle, lecturer at the Department of English, Stockholm University, for his professional and constructive comments on my English.

Finally I would like to express my thanks to the Council for the Renewal of Undergraduate Education who gave me the opportunity to engage in the dialogue with the teachers and students involved in the developmental projects by asking me to conduct this study. It is my pleasure to report the results of the evaluation to the Council with the hopes that it will encourage an ongoing discussion on the possibilities for realising a more inclusive kind of education.

Stockholm, January 1998

Inger Wistedt

1. Introduction

Changing Higher Education to Attract Women

In recent decades there has been a broad public debate in Sweden, as in many other countries, about the recruitment of female students to higher education in mathematics, science, and technology (e.g. Burton, 1990; Grevholm & Hanna, 1995). Few women choose to study these subjects at the tertiary level of education, too few to meet the demands of an expanding technological sector in society.

Why do women refrain from choosing science-related university programmes? The answers to the question build mainly on hypotheses about what characterises the interests of female learners, some founded on empirical investigations (Gilligan, 1982; Belenki, Blythe, Goldberger & Tarule, 1986; Harding, 1986). Mathematics, science and technology are, by tradition, male-dominated fields of interest and as such coloured by male priorities. The epistemological underpinnings of the teaching methods used within many science programmes have been criticised from a gender perspective on the grounds that such methods tend to disregard the social nature of knowledge formation (Burton, 1995; Hawkesworth, 1996). In areas where certain perspectives of the subject matter are viewed as 'objective' and value-free, variations in experiences and approaches to learning may not be appreciated: for instance, female experiences within a predominantly male community (*ibid.*, cf. Damarin, 1995; Boaler, 1997.

The move towards a perspective on teaching and learning as human practices rooted in conventions that may be challenged and that have to be challenged in order to attract new groups of students to science related studies can be viewed as a necessary evil, forced upon the educators for reasons of equality or for reasons of economical necessity. But there is a third reason for changing higher education to serve the interests of new groups of learners, a reason which focuses on change as a possibility rather than as a requirement.

Higher education is supposed to provide society with well- educated scientists. But the demands of society are rapidly changing. In the public debate it has been proposed that future mathematicians, scientists and technicians need a much broader education than is currently offered within universities and university colleges. Skills in handling complex problems of an interdisciplinary nature, competence in co-operating with others and in presenting scientific knowledge orally or in writing are qualities which are highly appreciated in the labour market but less highly valued within the current educational practices of mathematics, science and technology. Since female students are believed to have substantial experience in developing such skills it is possible to view female applicants to science programmes as a resource, bringing new competence to formerly male-dominated subject areas.

In 1992 an initiative to promote change in higher education was taken by the Swedish government. In a government bill (Prop. 1992/93:169) a special grant of 5 million Swedish crowns per annum over a three-year period was allocated with the aim of attracting new groups of students to university programmes where male, middle-class students are in majority. The study presented here is an evaluation of this initiative. It is based on data gathered within five development projects at the tertiary level of education which received funding through the government's initiative, projects with the aim of developing inclusive degree programmes designed to enhance female participation in areas of inquiry dominated by men.

The Government's Initiative

In September 1993 a letter of invitation was sent from the Council for the Renewal of Undergraduate Education to the presidents of Swedish universities and institutes of technology, inviting them to take part in a national competition for funds for development works. The letter manifested the intentions of the Swedish government, expressed in the bill mentioned above (Prop. 1992/93:169). The intentions were two-fold:

- *to broaden the recruitment of students* to science-related studies, above all the recruitment of female students, but also of male students with the wish to acquire broad competencies within the fields of mathematics, science and technology.
- *to enhance the quality of teaching within higher education* by encouraging new teaching methods that would appeal to these new categories of students and make the best of their capabilities.

In the Council's letter of invitation the applicants were encouraged to direct their project activities towards the students, and towards study programmes with a minority of female students, and they were invited to consider *"whether it would be possible to make use of forms of teaching that are more problem oriented than is currently the case"* (Letter of invitation, 1993 09 13, Council for the Renewal of Undergraduate Education, my translation).

In the review process, five universities each received about three to three and a half million crowns for development projects with aims and project plans that complied with the intentions and guidelines expressed in the Council's letter of invitation: The projects concerned new or revised degree programmes running from three to four-and-a-half years of study (120 to 180 academic credits). They were directed towards fields of study that currently attract few women, and they involved a re-thinking of the content and forms of teaching traditionally offered within science- related programmes (see Wistedt, 1996a for a comprehensive description of the initiative and the development projects).

The Aim of the Study

The study presented here was carried out during the introductory period of the programmes, from September 1995 to December 1997. The aim of the study is to evaluate the realisation of the main ideas that permeated the Government's initiative. The study focuses on the two goals described above: the recruitment aspect of the initiative, and the alternative work forms suggested as means for raising the quality of student learning and adapting the teaching methods to meet the demands of students who are not, by sex or previous training, accustomed to a scientific mode of thinking.

Have the five projects that received funding from the Council succeeded in fulfilling the aims expressed in the Government bill?

- Have the development projects been successful in their recruitment of new groups of students to the programmes, female students in particular?

- What characterises the teaching methods implemented within the programmes and in what respect can they be said to fill the students' needs in terms of developing their understanding of the subjects taught?

The Five Development Projects

The five development projects that received funding from the Council are located at five universities:

Two are Master of Science degree programmes of 160 academic credits (four years of full time studies): *Scientific Problem Solving* in mathematics, physics and environmental science at Göteborg University and *The Project Programme* in mathematics, mathematical statistics and physics at Stockholm University, each admitting about 30 students.

Two are Master of Science degree programmes in engineering of 180 academic credits (running through four and a half years of study): *Reforming the Computer Science and Engineering Programme, D++* at Chalmers University of Technology admitting about 100 students, and *The IT Programme* at Linköping University admitting about 30 students.

The fifth project is located at the University of Karlstad: *Women in Engineering Education*, which involves three programmes within the new engineering education comprising 120 academic credits (three years of full time studies). The programmes are directed towards the fields of *Computer Engineering, Energy and Environmental Engineering* and *Innovation and Design*, together admitting about 110 students. In 1995 a fourth programme was included in the project: *Structural Engineering*.

The five projects differ in many respects: Three of the projects concern new study programmes, offered as alternatives to traditional degree programmes within the respective faculties: *Scientific Problem Solving, The Project Programme, The IT-Programme*. At the University of Karlstad most of the programmes are fairly new (the oldest, the Energy Programme, was launched ten years ago). One of the five projects concerns a revised study programme, the *D++*. The content and forms of teaching differ within the programmes, the length of the programmes vary, as do the number of students admitted. The five projects are, however, parts of one developmental endeavour, funded by the Swedish government for the purpose of fulfilling two goals: to attract female students to male-dominated subject areas and to raise the quality of learning by making use of teaching methods that take into account the variation in the students' experiences and approaches to learning.

Defining Objectives for the Evaluation

In a previous study written in preparation for this evaluation, the five projects presented above were described in greater detail (Wistedt, 1996a). These descriptions were based on 22 interviews with project leaders and teachers engaged in the development projects and on written materials such as applications, programme descriptions, and information brochures produced within the projects.

The aim of the preparatory study was to form a basis for an integrated study of the programmes. If we wish to evaluate the initiative, rather than the individual projects involved, we need to see beyond the apparent differences in the organisation of the programmes, in search for some common rationales under which to subsume the observed variations.

Such common rationales were described in the preparatory study (*op.cit.*, p. 55-61): First of all the programmes were linked together by their common ambition to recruit new groups of students to the programmes, female students in particular. Secondly they were linked by their aspirations to adapt the teaching methods to these new groups of students. Two notions summarised the pedagogical ideas as they were expressed in the interviews with the teachers and project leaders:

- *the notion of the self-directed learner and*
- *the notion of the social character of learning*

The notion of the self-directed learner was expressed in a variety of forms in the interviews. In some way or another, all of the projects seemed to involve a breakaway from a view of learning as a linear process in which knowledge and skills are acquired in bits and pieces hierarchically organised, towards a view of learning as an increasing acquaintance with the subject matter in an experience based, spiralling process, in which students formulate and re-formulate their own frames of reference. An emphasis was put on learning as an act of acquiring a personal understanding of the course content rather than as an act of reproducing knowledge handed over by authorities.

The notion of the social character of learning was manifested on three different levels. On a personal level we found an emphasis on social interaction as a way to exceed the limitations of personal and idiosyncratic perspectives. Collective work forms, such as projects or problem-based learning, were favoured within the programmes, work forms that bear reference to a need for the individual to try out ideas of her own and test them in co-operation with others.

On a cultural level we found an emphasis on dialogue as a strategy for surmounting single-subject perspectives. Within most of the programmes, the students were given tasks which required the integration of knowledge from different subject areas, such as mathematics, physics, computer science and the like. Teachers from different subjects co-operated in planning the courses, in teaching and tutoring and in the process of assessing the students' knowledge.

On a social level we found a breakaway from the notion of university subjects as isolated institutions where students are socialised into limited perspectives, recruited to research rather than adapted to practices outside of the university. Many, but not all, of the teachers stressed the use of ”real-life” examples or ”scenarios” as bases for instruction. Such tasks introduce the students to a range of perspectives, some of which may be alien to a scientific or technological culture (humanistic, linguistic, social, etc.), or to the literate culture of the university in general (praxis oriented perspectives).

The following chapter presents the outline of the evaluation of the government's initiative, based on the results from the preparatory study (Wistedt, 1996a): a three-step evaluation which focuses on the goals as they were defined within the five development projects and expressed in the interviews with teachers and project leaders – the recruitment goal and the pedagogical goals common to all the projects.

Methodological Considerations Guiding the Evaluation

A Dialogical Evaluation

The word ”evaluation” has a variety of connotations, all linked to different views of the role of the evaluator – as a judge, as an expert reviewer, as a friendly observer, and a range of other roles (e.g. House, 1980; Bogdan & Biklen, 1982). The mode of evaluation in this study could be called dialogical since the study has been conducted in close contact and communication with teachers and students within the programmes as well as with interested parties outside of them: people who are not directly involved in the development work but who are interested in the outcomes of the projects. The role of the evaluator, in this case, resembles the role of a partner in a critical discussion of the aims and outcomes of the initiative.

As described in the previous chapter, the objectives of the evaluation were defined on the basis of interviews with teachers and project leaders, and the empirical studies presented in this report have all been designed in co-operation with teachers within the programmes. During the two years of evaluation, reports and articles have been written in which case-studies, based on interviews with students within three of the programmes, and observations of learning processes gathered in everyday settings, have been presented to the teachers and students involved in the development works (Scheja, 1996; Wistedt, 1996b; Wistedt, 1997; Wistedt, Brattström, & Martinsson, 1996). Preliminary versions of these reports have also been read and commented on by people who are not directly involved in the development works, such as physicists, mathematicians, computer scientists, and one representative from the labour market. Some of the studies have reached an international audience, and some have been published in international journals and discussed in seminars and symposia (Wistedt, 1996a; Wistedt, in press; Wistedt, Brattström, & Martinsson, 1997).

Outline of the Report

The study presented here summarises the results from the case-studies referred to above. The discussion is thematically organised:

The next, i.e. the second section of this report shows an overall picture of the *recruitment aspect* of the programmes, based on statistical analyses of data comprising all students entering the programmes in 1995 and 1996, that is entrants during the first two years in which the projects were put into practice.

The third section of the evaluation has the form of an in-depth study of the *pedagogical aspects* of the programmes – the problem-oriented teaching methods and the co-operative and interdisciplinary work forms implemented to serve the interests of new groups of students.

In a fourth and concluding part of this report the results from these empirical studies are discussed in relation to the programmes' inclusive enrolment policies and in relation to the overall aims of the government's initiative.

Notes on Methodology

Since the research methods used within this evaluation range from quantitative methods of gathering and analysing information to qualitative analyses of data from interviews and observations, the specifics of the methodological approaches used will be discussed in the following chapters and in relation to the studies presented. However, some short notes on methodology, of a more general nature, will be presented in this introductory section of the report.

Quantitative Studies of the Recruitment Aspect of the Initiative

As mentioned, the study of the recruitment to the programmes has the form of a census covering all students entering the programmes in 1995 and 1996. The aim of the study is to establish an overall picture of recruitment trends, which means that we need to define what we mean by 'recruitment'.

Recruitment could be defined in terms of 'enrolment', in which case we would look at the total number of students entering the study programmes and the proportion of female students among them. In order to evaluate the recruitment results we would like to compare the proportion of women within the programmes involved in the development projects with the proportion of women within comparable study programmes at the tertiary level of education. Since the recruitment ambitions also involved the recruitment of students from non-traditional student categories, for instance students who do not have a natural science background, the overview also includes data about variables other than sex, for instance previous education. Such data about the students entering the programmes in 1995 and 1996 are presented in the overview and the recruitment results are compared to the results available in the national statistics (SCB, 1997).

By 'recruitment results' we could also mean results that are fairly stable over time. When the programmes where launched in 1995 they attracted a lot of attention from the media. Local newspapers took an interest in the development projects and policy makers put a lot of effort into marketing the programmes. This means that we have to consider certain implementation effects on the recruitment, which may eventually fade away. One limitation to this study is that it only includes data from the first two years of the programmes, data available within the administration offices at the respective universities. This evaluation has been carried out during the on-going implementation of the programmes, and none of the students have, as yet, completed their studies. This means that we cannot evaluate the long term effects of the development works. We can, however, provide a broad picture of the recruitment trends, which will be discussed in the overview.

Since the teachers and administrators do not only expect the students to enter the programmes, but also want them to stay and eventually receive a degree, we need to broaden the definition of 'recruitment' to include the drop-out rates as well as data about how different categories of students succeed in their studies. In the overview we present data about the academic results of students enrolled in 1995. The data comprises results from ordinary course assessments in mathematics and a supplementary core subject (such as physics), and the results on project assessments for different categories of students. The data has been provided by the teachers engaged in the projects, and by the administrative offices at the various universities.

Qualitative Studies of the Pedagogical Aspects of the Programmes

It is costly in terms of time and research effort to design and carry out a qualitative study of the pedagogical aspects of the programmes, that takes the variation among them and among the students attending them into account. The dialogical approach presupposes a close contact between the researcher and the subjects. A relationship of trust must be built which permits a critical and fruitful discussion of the alternative teaching methods implemented within the programmes.

In the preparatory study we proposed a design for a less time-consuming evaluation. In the yearly meetings on the projects, arranged by the Council, we suggested a qualitative study that could be carried out within the time limits of the evaluation (40% of a full-time employment during 2.5 years, see Wistedt, 1996a, p. 71). We have not been able to carry out these plans. In Karlstad it took some time to implement the pedagogical ideas put forward in the project plan. *"The step is surprisingly big when you move from traditional teaching methods to student oriented ways of teaching*", says one of the teachers in a progress report (Renström, 1997). In the years during which this evaluation was carried out, the Karlstad project was first and foremost a recruitment project. In Linköping, the teachers argued that the students did not have the time to set aside for participating in the evaluation. *"The students are constantly visited by people who want to evaluate and interview them"*, said one of the teachers in an e-mail letter (my translation) and another teacher found it hard for the students to take part in the evaluation with the argument that *"It is very important that the students have the time to concentrate on their studies"*.

Such reactions are understandable. The IT-programme involves radical changes in teaching philosophies, perhaps the most radical within the initiative. Inspired by teaching methods developed within the fields of health-care and medicine at Linköping University, the project leader drew up the lines for an initiative founded on the basic concepts of Problem-Based Learning (Barrows & Tamblyn, 1980; Boud, 1987; Berkson, 1990; Engvig, 1997). The IT Programme is the first study programme in Engineering in the world which is built in its entirety on PBL. Such a radical turn in teaching philosophies is bound to attract attention. During the implementation years the programme was scrutinised by critics and interested parties within and outside of the university, and as a consequence the students were the subjects of investigations to a greater extent than is reasonable. The comments from the teachers, cited above do, however, reveal a view of evaluation as something bothersome, something which serves the interests of the receivers of the information rather than the interests of those directly involved in the development projects. Evaluation is perceived as something which is *done to* the students and the teachers, giving very little in return.

It takes time to change such views of evaluation, and it has not been possible, within the time-limits of this evaluation, to establish workable relationships with teachers and students at all five of the universities and in all seven of the programmes. Given an opportunity to experience an alternative approach to evaluation, students may, however, find that it can serve their interests as well as the interests of those who seek information about the merits and limitations of the pedagogical ideas permeating the programmes. The students at Göteborg University, for instance, participated in three of the case-studies on which this report is based. The first study was carried out in 1996, during their second term in the programme for Scientific Problem Solving (Wistedt, Brattström, & Martinsson, 1996; 1997). Twelve students volunteered to take part in this study. In a second study, carried out during their third term, all 24 students volunteered, and they were very keen on making sure that they would have an opportunity to read that study as well (Wistedt, 1997; in press). Obviously the students felt that they had something to gain by participating in the evaluation.

The in-depth studies presented in part three of this report are based on data gathered within three of the development projects: *Reforming the Computer Science and Engineering Programme, D++*, at Chalmers University of Technology, *Scientific Problem Solving*, at Göteborg University, and *The Project Programme* at Stockholm University. Figure 1 below gives an overview of the four case-studies used as data for the evaluation of the pedagogical aspects of the projects:

Case study 1: Mathematical problem solving – ways of understanding mathematical induction (presented in Wistedt, Brattström, & Martinsson, 1996; 1997).

University	Method	Teachers	Groups	Students	Female	Male
Stockholm	Observation		3	11	3	8
Göteborg	Observation		3	12	6	6

Case study 2: Mathematical problem solving in computer science and engineering.

University	Method	Teachers	Groups	Students	Female	Male
Chalmers	Observation		4	29	11	18
Chalmers	Interview			5	4	1
Chalmers	Interview	4				

Case study 3: Project assessment in physics, mathematics and mathematical statistics (presented in Wistedt, 1997; in press).

University	Method	Teachers	Groups	Students	Female	Male
Göteborg	Observation	3	4	24	12	12
Göteborg	Interview	6				

Case study 4: Students' assessments of the first year of study (presented in Scheja, 1996; Wistedt, 1996b)

University	Method	Teachers	Groups	Students	Female	Male
Stockholm	Interview			14	2	12
Göteborg	Interview			7	4	3

Figure 1: An overview of the four case-studies used in the qualitative part of the study. Location for interviews and observations, total number of teachers, groups and students observed or interviewed, and number of female and male students.

Figure 2 below gives an overview of the data, the total number of observations and their duration, the number of students observed and the number of female and male students among them, the number of interviews that have been carried out and the number of students and teachers who have been interviewed.

Observations					**Interviews**				
Number	Duration	Students observed	female	male	Number	Students interviewed	Female	Male	Teachers interviewed
26	1/2–1h	76	32	44	34	26	10	16	10

Figure 2: An overview of the data

Since some of the students are the same in two or more of the case-studies the total number of *different* students involved in the qualitative part of this evaluation is 65 (27 women and 38 men), which is a rather large number for a qualitative study. These students are not chosen to represent the other students (604 in all enrolled in 1995 and 1996). The case-studies do not aim at statistical generalisations about the students' attitudes and approaches to learning. Rather they aim at in-depth descriptions of learning activities in situations which are problem oriented, co-operative and interdisciplinary, that is, situations which have characteristics favoured within all of the programmes. The aim is to provide cases for the development of a thorough understanding of how such forms of work may influence the ways in which the students approach the subject matter.

These cases would have been stronger if we had had the opportunity to include data from the University of Karlstad and *The IT-programme* in our study. On the other hand, since the students at Linköping are reported to have been the subjects of a lot of investigations and evaluations, we can expect many interesting and in-depth studies to results from them. When these studies are published we will have an opportunity to compare the results from this evaluation to the results of these studies. This means that we may look forward to a continuing dialogue about the development projects involved in the government's initiative.

2: Overview

Recruitment Results

How Many Female Students are Enrolled in the Programmes?

One of the goals expressed in the government bill (Prop. 1992/93:169) was to increase the number of women within university courses in mathematics, science and technology. In the academic year 1995/96 the proportion of women among university entrants to master of science programmes in engineering and to the new engineering programmes increased by 2 percent over the previous year. Of the 13,777 students entering university courses in science and technology in 1995, 23% were women. The proportion of women among undergraduate entrants in mathematics was 28%, in physics 23% and 17% in master of science programmes in computer engineering (SCB, 1997, p. 48).

How do the programmes that received funding from the Council for the Renewal of Undergraduate Education stand in comparison? One answer to the question is given below (Table 1) in raw figures and percentages.

Table 1: Proportion of female students within each programme. Total number of entrants in 1995 and 1996. Female entrants in raw figures and percentages.

University	Programme	1995			1996		
		Total	Female	%	Total	Female	%
Chalmers	D++	106	16	15	111	21	19
Göteborg	Scientific Problem Solving	33	18	55	34	19	56
Karlstad	Computer Engineering	46	7	15	65	10	15
Karlstad	Energy & Environmental Eng.	18	5	28	31	9	29
Karlstad	Innovation & Design	20	3	15	22	10	45
Linköping	The IT Programme	35	14	40	35	17	49
Stockholm	The Project Programme	23	7	30	25	9	36
Total		281	70	25	323	95	29

As is evident, the proportion of female entrants varies substantially. The two programmes within the field of computer engineering have the lowest percentage of female students, slightly below the average of 17%. The IT Programme, however, a master of science programme with a similar profile, has the second best recruitment results in 1995 as well as in 1996. The two academic programmes in mathematics and physics score well above average.

The variation in percentages may be explained by the fact that the programmes in computer science and engineering at Chalmers, and to some extent the computer programme at the University of Karlstad, are reformed programmes while the other programmes are new. It may be easier to attract new groups of students to programmes which do not have a history. If men's and women's educational choices are bound by tradition, it may be difficult to recruit women to programmes that are known to be strongly dominated by men, even if an extra effort is put into making them more attractive to women. It may take some time to implement a new ideology. Two years is too short a time to evaluate long term effects of the development work.

The differences in the recruitment of female students may also have to do with differences in admission procedures. Within the three programmes which have the highest proportion of female entrants, the applicants were encouraged to write short biographical sketches and to describe their reasons for choosing the programmes (Wistedt, 1996a). These essays were used as part of the admission procedure. An investigation of how they affected the possibilities for individual students to enter the programmes was carried out at Göteborg University (Wistedt, 1996b). The results show that they did not have a direct effect on the recruitment results, although some students could climb considerably (up to 20 positions) in the ranking-list by writing a well-argued and convincing essay. In the final intake, however, many of the applicant at the top of the list withdrew their applications and all those who had climbed to more favourable positions would have been admitted anyway. Nevertheless, the procedure of supplementing the application files by essays may have played an important role as a policy marker. Women may have been encouraged to apply by the mere fact that qualifications other than grades were explicitly appreciated within the programmes, for instance communicative skills which are not traditionally associated with subjects such as mathematics or physics. This may have encouraged women to apply to these programmes to a greater extent than to programmes where the admission procedures had not been reconsidered. More female applicants means that there are more competent women to choose from and therefore a greater proportion of female entrants who can compete for the course places.

At Chalmers the proportion of women increased in 1996. General statistics is not yet available, and hence we do not know if the increase is part of a general trend or an effect of the recruitment campaign. As can be seen in

Table 1 the number of female students increased in all of the programmes in 1996 (with one exception). Most tangible is the rapid change at Innovation & Design in Karlstad, a programme which is, however, relatively small.

Thus far the results seem promising. When recruiting, however, we not only expect women to enter the programmes; we also want them to stay. In Table 2 below, we have excluded drop-outs from the statistics (as reported in March 1997 when data was gathered). Observe that students who were enrolled in 1995 have had an extra year to reconsider their choices of programme which means that the numbers are not comparable from year to year. On the other hand, drop-outs seem to be less frequent during year two: one student was reported to have dropped out from D++ during the third term, five from Scientific Problem Solving and two from the Project Programme.

Table 2: Proportion of female students within each programme. Total number of students enrolled 1995 and 1996, not reported as drop-outs in March 1997. Female students in raw figures and percentages.

University	Programme	1995			1996		
		Total	Female	%	Total	Female	%
Chalmers	D++	94	11	12	102	19	19
Göteborg	Scientific Problem Solving	25	12	48	28	16	57
Karlstad	Computer Engineering	43	7	16	62	9	15
Karlstad	Energy & Environmental Eng.	18	5	28	30	9	30
Karlstad	Innovation & Design	19	3	16	20	8	40
Linköping	The IT-programme	35	14	40	34	16	47
Stockholm	The Project Programme	13	1	8	22	9	41
Total		247	53	21	298	86	29

The most drastic changes are found at Stockholm University where all the women but one dropped out during the first year. This, however, seems to be an effect of a poor recruitment to the programme (many of the entrants were applicants for whom this programme was not the first choice) in combination with implementation problems during the first year. In 1996 the situation had stabilised, and the percentage of female students rose to 41%, most of them still enrolled in the programme. Many of the 1995 drop-outs left the programme early, before they had had a chance to form an opinion of the content and form of the courses. In telephone interviews conducted in March 1996, the late drop-outs were asked about their reasons for leaving. Poor study results and a heavy working load were the main reasons given. None of the interviewees complained about the new pedagogy:

"No the projects were the best part of it all". One of the female drop-outs said, however, that she had expected more of the projects: *"I thought that they were supposed to engage us in experimenting, not just reading and summarising what others already had found out"*.

Which Students Leave the Programmes?

The Stockholm example calls for a more thorough investigation of which students are leaving the programmes. The intentions expressed in the government bill were to broaden the recruitment of underrepresented categories of students to higher education in mathematics, science and technology, female students in particular. If female entrants tend to leave the programmes to a greater extent than male students do, it is cause for concern. Table 3 below gives an overall picture of the drop-out rates.

Table 3: Tendency to leave the programmes. Total number of students enrolled 1995 and 1996, female and male drop-outs in numbers and percentages of each sex-group.

	Number of students	Number of drop-outs	% drop-outs
female	165	26	16
male	439	33	8

Judging from Table 3, female students seem to leave the programmes to a greater extent than male students do. However, caution has to be exercised when interpreting the figures. One has to bear in mind that the students are not a homogenous population: They come from seven programmes at five universities, with different recruitment profiles and different goals, and, in particular, different sex ratios and drop-out rates. This could bias the figures quite severely. For instance, suppose that one of the programmes has a high drop-out rate for both sexes (relative to the other programmes), and also a large proportion of female students. This could produce a result such as the one shown, without a single individual programme having a higher percentage of women than men leaving the programme! Under these circumstances the total percentages would be somewhat misleading. In order to avoid this sort of ambiguity, we supply a break-down of the percentages into individual programmes, as shown in Table 4. This will enable us to compare drop-out rates for each programme separately.

Table 4: Tendency to leave the programmes: Female and male drop-outs in each programme as reported in March 1997. Total number of female (f) and male (m) students enrolled 1995 and 1996, number of male and female drop-outs in numbers and percentages of each sex-group.

University	Programme	Sex	Number	Drop-outs	% drop-outs
Chalmers	D++	f	37	7	19
Chalmers	D++	m	180	14	8
Göteborg	Scientific Problem Solving	f	37	9	24
Göteborg	Scientific Problem Solving	m	30	5	17
Karlstad	Computer Engineering	f	17	1	6
Karlstad	Computer Engineering	m	94	5	5
Karlstad	Energy & Environmental En	f	14	0	0
Karlstad	Energy & Environmental En	m	35	1	3
Karlstad	Innovation & Design	f	13	2	15
Karlstad	Innovation & Design	m	29	1	3
Linköping	The IT-programme	f	31	1	3
Linköping	The IT-programme	m	39	0	0
Stockholm	The Project Programme	f	16	6	38
Stockholm	The Project Programme	m	32	7	22

Table 4 shows that the tendency persists for individual programmes: the drop-out rate is higher among women. To see whether the tendency is statistically significant, we have used the Mantel-Haenszel test, which compares rates within each programme, not between programmes[1]. To test significance at the 5% level, we compute the Mantel-Haenszel test statistic, and compare it with the 95th percentile of a χ^2 distribution with one degree of freedom; this percentile turns out to equal 3.84. A value of the Mantel-Haenszel statistic greater than 3.84 is significant, a smaller one is not. Naturally, the larger the value, the more convincing the tendency. The Mantel-Haenszel test statistic for Table 4 turns out to be 5.62, and we conclude that the difference is statistically significant at the 5% level.

However, before we draw any conclusions we need to know whether there are variables other than sex involved in producing the results. In the

[1] In this report we will use the Mantel-Haenszel test whenever we are inquiring about general differences between sexes or between different groups of students, since it could well be that percentages differ between programmes as well as between sexes or student groups.

recruitment campaign other variables were also in focus. As mentioned above, three of the programmes also included a rethinking of the admission procedures as part of the development work. In all of the programmes the primary basis for admission was grade-point average from upper-secondary school or the results from the national university aptitude test, but in three of the programmes the students were also admitted on the basis of written essays. This procedure was meant to favour new groups of students, for instance students from non-traditional student categories (see Wistedt, 1996a), applicants with a more varied background than is usual among entrants to higher education in mathematics, physics and technology.

On the basis of such written essays, sent in by applicants to the Project Programme and Scientific Problem Solving, four categories of students were identified. The categories were later operationally defined to suit the programmes where we did not have access to student essays:

- **New recruits**: Students who come directly from the Natural Science Programme or the Technology line at the upper-secondary school.

- **Experienced students**: Students who have an upper-secondary certificate within the fields of natural science or technology and who have, in addition, experiences (credits) from tertiary education.

- **Re-starters**: Students who have an upper-secondary certificate within the fields of natural science or technology and, in addition, work experience credits, but not credits from tertiary education.

- **Career-shifters**: Students who do **not** have a background within natural science or technology, who for instance have an upper-secondary certificate from the Social Science Programme, and who have acquired the necessary entrance qualifications by attending supplementary natural science courses.

The graph below shows the distribution of categories within the programmes. The distribution does not change much from 1995 to 1996. It varies, however, between the programmes. Karlstad and Linköping are the two extremes – Linköping with a high proportion of category A students, Karlstad with a high percentage of category C students. All three programmes in Karlstad have a similar distribution and the three programmes have therefore been conflated in the graph.

Category by Project

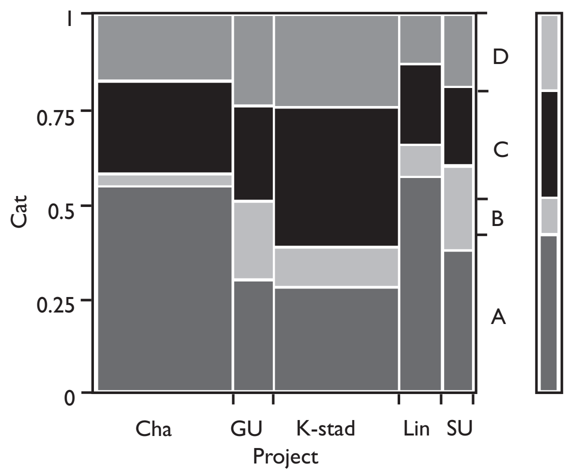


Figure 3: Distribution of categories within the development projects: Chalmers University of Technology, D++(Cha), Göteborg University, Scientific Problem Solving (GU), Karlstad (K-stad), Linköping University, The IT Programme (Lin), Stockholm University, The Project Programme (SU).

When discussing drop-out rates category D students are the most interesting, since this category singles out students from non-traditional groups. Table 5 below shows the number of category D students within each of the five development projects and the drop-out rates within this category in numbers and percentages.

Table 5: Tendency to leave the programmes: Students who do not have a natural science back-ground (Category D: career-shifters). Number of students in categories D or O (Others, i.e. A: new recruits, B: experienced students and C: re-starters) who entered the programmes in 1995 and 1996. Number of drop-outs within each category in raw figures and percentages.

University	Programme	Sex	Number	Drop-outs	% drop-outs
Chalmers	D++	O	179	10	6
Chalmers	D++	D	38	11	29
Göteborg	Scientific Problem solving	O	51	7	14
Göteborg	Scientific Problem Solving	D	16	7	44
Karlstad	Computer Engineering	O	75	4	5
Karlstad	Computer Engineering	D	32	1	3
Karlstad	Energy & Environmental En	O	44	1	2
Karlstad	Energy & Environmental En	D	5	0	0
Karlstad	Innovation & Design	O	30	2	7
Karlstad	Innovation & Design	D	12	1	8
Linköping	The IT-programme	O	61	1	2
Linköping	The IT-programme	D	9	0	0
Stockholm	The Project Programme	O	39	9	23
Stockholm	The Project Programme	D	9	4	44

The table shows that Category D students tend to leave the programmes to a greater extent than students from other categories. The Mantel-Haenszel test statistic is 16.3, a significant result and a convincing tendency.

If we exclude category D students and investigate the relationship between sex and drop-out rates the Mantel-Haenszel test gives 1.33 which is not significant. If we, on the other hand, exclude the female students and investigate the relationship between category and drop-out rates we get 4.83, which is significant, and if we exclude the men and investigate the same relationship the test statistic is 7.67, even more convincing. Thus it seems reasonable to conclude that the seemingly high proportion of female students leaving the programmes cannot be attributed to sex only.

The results this far seem to imply that there is a possible connection between the variables sex and category D. Table 6 below shows, for each programme, the share of female and male students who belong to category D.

Table 6: Proportion of female and male students within the programmes, enrolled 1995 and 1996, and belonging to category D. Total number of students within each programme. Category D-students in total numbers and percentages of each sex-group.

University	Programme	Sex	In total	D	%
Chalmers	D++	f	37	11	30
Chalmers	D++	m	180	27	15
Göteborg	Scientific Problem Solving	f	37	7	19
Göteborg	Scientific Problem Solving	m	30	9	30
Karlstad	Computer Engineering	f	17	10	59
Karlstad	Computer Engineering	m	94	22	23
Karlstad	Energy & Environmental En	f	14	2	14
Karlstad	Energy & Environmental En	m	35	3	9
Karlstad	Innovation & Design	f	13	6	46
Karlstad	Innovation & Design	m	29	6	21
Linköping	The IT-programme	f	31	7	23
Linköping	The IT-programme	m	39	2	5
Stockholm	The Project Programme	f	16	4	25
Stockholm	The Project Programme	m	32	5	16

Category D-students seem to be over-represented among women. The Mantel-Haenszel test confirms this: 11.5, which is significant. This means that we have to dig more deeply in order to understand what lies behind the drop-out rates.

From the interviews with drop-outs at the Project Programme we have learnt that students give poor study results as one of the reasons for leaving the programme. Do female students, or category D students, perform less well within the programmes? We also have learnt that the students seemed satisfied with project work. In interviews with teachers engaged in the development activity, the interviewees expressed their beliefs in alternative ways of teaching as serving the interests of new groups of learners, female students in particular (Wistedt, 1996a). How do students from different categories meet course demands of different kinds?

How Well Do the Students Succeed?

In March 1997 data was gathered about the results of students enrolled in 1995. Test results and grades were reported from two ordinary assessments in mathematics and two tests given in one or two supplementary core subjects, covering the first three terms. (The results from Stockholm and Linköping are based on one test in mathematics and one in an additional subject.) Students carried out projects only at the Project Programme, Scientific Problem Solving and D++. Results were reported from two projects in Stockholm and Göteborg and from one project at D++. The IT-programme is, as mentioned above, based on the principles of problem-based learning, which means that the students work in groups with vignettes, not with projects in the traditional sense. At Karlstad the students receive credits for their results on tests and laboratory work, not on projects separately, hence there are no project results available for these two programmes.

Again we investigate the variables sex and category D, now regarding study results from courses and projects. Such variables are not comparable between different programmes, they are not even comparable within single programmes. As we know, the tasks which provide the bases for assessments can differ a great deal in difficulty. Care should be taken not to over-interpret individual results or to compare results between or within programmes. The aim of this study is not to evaluate the success of the programmes but to develop a picture of trends: Do, for instance, female students within each programme tend to succeed better on projects than the male students do, or do students from certain categories have greater difficulty in meeting course demands than students from other categories when we use the same assessment procedure to measure their study results?

Since the figures are not directly comparable between programmes in any case, we have chosen to define ”satisfactory” in such a way as to yield groups of approximately the same size in all of the programmes. This means that we define ”satisfactory” as having passed all courses and projects, except in Linköping where we consider students as ”satisfactory” if they have passed one of the two courses reported.

Table 7: Female and male students who have satisfactory results from examinations within the programmes (based on reported test results for students enrolled 1995).Total number of students in each sex-group. Female(f) and male(m) students who have satisfactory results from course examinations and project assessments, in raw numbers and percentages.

University	Programme	Sex	Total Number	Courses	%	Projects	%
Chalmers	D++	f	16	4	25	9	56
Chalmers	D++	m	90	49	54	76	84
Göteborg	Scientific Problem Solving	f	18	7	39	10	56
Göteborg	Scientific Problem Solving	m	15	5	33	3	20
Karlstad	Computer Engineering	f	7	5	71	-	-
Karlstad	Computer Engineering	m	39	23	59	-	-
Karlstad	Energy & Environmental En	f	5	2	40	-	-
Karlstad	Energy & Environmental En	m	13	8	62	-	-
Karlstad	Innovation & Design	f	3	2	67	-	-
Karlstad	Innovation & Design	m	17	10	59	-	-
Linköping	The IT-programme	f	14	2	14	-	-
Linköping	The IT-programme	m	21	7	33	-	-
Stockholm	The Project Programme	f	7	2	29	2	29
Stockholm	The Project Programme	m	16	9	56	12	75

There is no apparent pattern. If we investigate the relationship between sex and course results the Mantel-Haenszel test gives 3.00, which is not significant. If we exclude drop-outs we get 0.824, which is not significant either. The results on projects point in different directions: In some programmes the female students do better on courses than the male students do, in other programmes female students receive higher grades than male students on project examinations. There is no general tendency for female students to do better on examinations following certain types of course work. The Mantel-Haenszel test confirms this. The result on the statistic is 1.33, or 0.54 if we consider drop-outs.

But what about category D students? The alternative work forms were implemented in order to raise the quality of teaching. In the interviews with teachers engaged in the development works (Wistedt, 1996 a), the interviewees described how they were moving from a culture-centric teaching practise, relying heavily on standardised means in the form of lectures, exercises and tests, towards a more relativistic view of teaching, relative, for example, to variations in the process of learning (*ibid.*, p. 55). The alternative work forms were meant to favour all students, but in particular students from non-traditional groups. Category D students have a varied background, but they have one thing in common – they do not have the traditional educational background, that is an upper-secondary certificate within the fields of natural science and technology, which means that they have less experience of a natural science or mathematics culture than the other students do.

Table 8 below, shows how category D students succeed on course examinations and project assessments. If the policy plans have been successfully implemented, we would not find any substantial differences when comparing the results given in table 7 and the results reported below.

Table 8: Students of different categories who have satisfactory results on examinations: D (career-shifters) and O (Others, i.e. categories A, B and C), based on reported results for students enrolled 1995. Total number of students in each category. Students who have satisfactory results on course-examinations and project-assessments in raw numbers and percentages.

University	Programme	Sex	Number	Courses Total	%	Projects	%
Chalmers	D++	O	90	50	56	76	84
Chalmers	D++	D	16	3	19	9	56
Göteborg	Scientific Problem Solving	O	26	9	35	11	42
Göteborg	Scientific Problem Solving	D	7	3	43	2	29
Karlstad	Computer Engineering	O	30	21	70	-	-
Karlstad	Computer Engineering	D	12	6	50	-	-
K-stad	Energy & Environmental En	O	18	10	56	-	-
Karlstad	Energy & Environmental En	D	0	0	0	-	-
Karlstad	Innovation & Design	O	17	11	65	-	-
Karlstad	Innovation & Design	D	3	1	33	-	-
Linköping	The IT-programme	O	29	9	31	-	-
Linköping	The IT-programme	D	6	0	0	-	-
Stockholm	The Project Programme	O	20	10	50	12	60
Stockholm	The Project Programme	D	3	1	33	2	67

In general, students of category D do less well on course examinations than students from other categories. The Mantel-Haenszel test gives 8.04 which is significant. Project examinations do not seem to cause the same difficulties. The Mantel-Haenszel test gives 3.66 which is not a significant result. This may, however, be an effect of the assessment procedures. Most of the teachers involved in these new programmes have less experience in assessing individual knowledge acquired through co-operative work forms than in designing course examinations. It is not an easy task to assess student knowledge which is produced in co-operation with peers. It is possible for some students in a study group to pass on the basis of a weaker performance than some other students. Also note that the results from Göteborg University differ from the main trend. D-students seem to cope quite well with the course demands within Scientific Problem Solving. When we investigate the students' results on projects, the number of programmes is reduced which means that the results from Göteborg University has a greater impact on the overall results. This means that we cannot, as yet, draw any definite conclusions about our findings.

The issue of assessment will be brought into focus later in this study. For the moment we have to rest with an unsubstantiated impression – that category D students have greater problems than other categories of students in coping with the course demands. Since category D students are relatively few, 47 women and 74 men, and since we would have to perform several tests on the same data set in order to further the investigation of the relationship between category, sex and assessment results, we cannot confirm the impression statistically. It may, however, seem as if we are dealing with a vulnerable group of students, a group which also happens to be one of the targets of the recruitment campaign – students who did not choose science-related programmes at the upper-secondary school but who have reconsidered their career choices and who have devoted substantial time and effort to acquiring the competence needed for admission, and furthermore a group in which female students are over-represented. The development projects do not seem to have succeeded in adjusting their teaching methods to meet the demands of this group.

On the other hand, we know very little about these demands. The statistical model groups together students with some common characteristics, in this case a common feature of their educational background, but it also hides possible variation within the group, for category D is far from homogeneous. Some short excerpts from much longer essays written by female students in applying to the programme for Scientific Problem Solving will exemplify the many roads that can lead to the decision to apply to a programme within subject areas which have not been considered before:

"I have just completed one year of studies at the Basic Course in Natural Sciences. I chose to become a teacher in mathematics and physics, but when I applied I did not know of your programme, which I find would suit me perfectly. /…/ At the upper-secondary school I took the easy way out and did not choose the Natural Science Programme. I chose 'Advertising and Decoration' and I have been working within the field of advertising for the last 15 years, starting as an AD-assistant and ending as a project leader for advertising campaigns…"

"I am 21 years old and two years ago I received my Upper-Secondary Certificate in the Social Science Programme. When the time came to apply to university I found that I had to supplement my education in order to be able to choose the courses I wanted to attend. Now I have completed one year of studies within the Basic Course in Technology./…/ My choice of your programme is based on the belief that it would suit my interests and aptitudes. Physics is my favourite subject. My conviction is that more women with a broad education in mathematics and technology are needed in society. Not because we are better than men, but because many questions, especially questions that have to do with our environment, need to be addressed by people with different backgrounds and different perspectives…"

"I am 31 years old and a mother of two children. For the last ten years I have worked as a secretary and an educator. I have an upper-secondary certificate from the three-year economics line. I have travelled a lot and I have also worked abroad for a couple of years and I have a fairly good knowledge of English and Spanish. /…/ This autumn I have taken supplementary adult education courses in the natural sciences and mathematics. Mathematics has always appealed to me. Physics, on the other hand, is a subject that I have always thought of as a bit 'scary'. My interest in the subject has, however, changed radically since I started my further education…"

These students vary in age, in interests and in vocational experiences. There is very little in their background which could readily explain why they would have common problems in coping with course demands. One possible explanation, however, is that these problems have to do with their previous training. Do they, for instance, have lower grades than other categories of entrants?

Grades From Upper-Secondary School

About 60% of the students were admitted to the programmes primarily on the basis of grade-point average from the upper-secondary school. The diagram below (Figure 4) shows grade-point average for different categories of students admitted to the programmes in 1995 and 1996.

Grade by Category

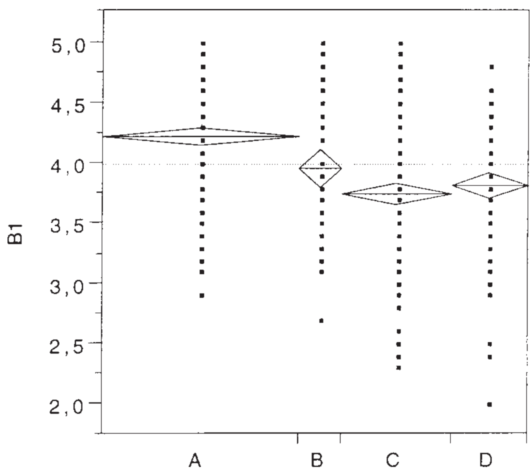


Figure 4: Grade point average for different categories of entrants in 1995 and 1996 as reported by the admission office (B1 is the official code for the registration of grade point average): A (new recruits), B (experienced students), C (re-starters) and D (career shifters).

About 40% of the students were admitted on the basis of results from the national university aptitude test, in some cases in combination with work experience credits. For some of these students we do not have access to grade point average. We lack information for about 3% of the students at the IT-programme and 35% of the students at D++. For all the other programmes we have the necessary information.

Considering these limitations of the data, we find that category D students have significantly lower grades than the other categories of entrants taken as a group, and the tendency is the same within all of the programmes. Grade point averages for category D students differ from those of the other categories by 0.09 (at Linköping University) up to 0.21 (at Göteborg University) on a five-point scale. Can this explain their poorer results?

We would expect the differences in study results to disappear when we compare category D students to other students within the same programme who have approximately the same grade point average. We have performed a number of statistical tests where we have tried to substantiate this expectation, but the tests gave inconclusive results when we corrected for grades.

This means that the questions raised above about the alternative ways of teaching and their suitability for different categories of students remain to be answered. In order to shed light on the issues we cannot rely solely on statistical methods. In the in-depth studies presented below we address the questions from a qualitative point of departure.

3: In-depth studies

Student Perspectives on the Forms of Work

An assumption often expressed about female learners is that they prefer working in groups and in close contact with teachers and peers. Such assumptions have, to some extent, formed the basis for the Government's initiative and the programme policies as they were described in the interviews conducted within the preparatory study (Wistedt, 1996a, p. 63-67). Beliefs about the relationship between certain work forms and female competences, such as social skills, also find support within the feminist literature, where researchers often call for collaborative modes of working that will stimulate dialogue between students and between students and teachers (e.g. SOU 1995:110, p. 260; Cordeau, 1993, p. 127). Some feminists even argue for the existence of female ways of knowing (Belenky, et al, 1986), female ways of thinking (Gilligan, 1982), and female ways of reasoning (Sherwin, 1994, p. 21. For a critique of these views see Frye, 1994; Hanna, 1994; Hawkesworth, 1996).

What characterises the new ways of working implemented within the programmes and in what respects can they be said to meet the students' needs in terms of developing their understanding of the subjects taught? In individual interviews with first-year students at *D++,* three female students expressed their views on the collaborative work forms. Did they like working in groups?

> *– No, I don't really think I do. I cannot concentrate when I'm in the group. Often I can't. I think much better when I am on my own. Mathematics is a good example. I had the impression that I understood almost nothing of the mathematics we had studied in the group. And then, at the course-examination, everything got quiet around me and I was in my own world, and suddenly I understood it all.*

She said that she is too sensitive to the social environment to benefit from group work:

> *– Because when I am in the group I don't take the time to think for myself.*

When the interviewer told her that one argument for implementing the collaborative work-forms was that they were supposed to benefit female students precisely **because** these students were believed to be socially skilled, she laughed heartily.

Another female student described the work forms in the following way:

– *There are many well-formulated arguments for group work. They are new and faddish and they are supposed to suit women.*

– *And do they?* the interviewer asked.

– *Well, I don't know. In a way they do. But there is a problem with group work: it tends to go off the rails. Maybe our group is too big. We are eight or nine people, and most of us really want to work, but still there is always someone who starts talking about other matters. But then again, you never know what you learn. Maybe we learn more than we think we do. If you are at home cramming and reproducing formulas it is much easier to get hold of what you learn than it is when you discuss the matters in a group.*

A third female student expressed her views as follows:

– *Personally I want to get things done. If I spend eight or ten hours in class I really want to learn something. That is the feeling I have, since… I don't know… maybe it's because I'm 27 years old and I am in a bit of a hurry.*

In the previous chapter we posed a question about the alternative ways of teaching and their suitability for different categories of students. Obviously we cannot address the question in such a generalised way. What the students above point to is that the forms of teaching must be discussed in relation to the aims of the activities as the students interpret them. Teaching methods are not good or bad in general; they are either suited or unsuited to the specific purposes of learning. Discussing everyday topics in a group of friends is one thing; to solve intellectual problems in a group of peers is quite another thing. That women have more experience in communicating in small groups in their daily lives (e.g. Coates, 1988) does not imply that they automatically benefit from group-work when confronted with tasks of a different kind in an educational setting. Skills are not easily transferable (cf. Larkin, 1989; Säljö, 1991).

This means that we need to qualify the issue if we want to shed light on the pedagogical aspects of the programmes. In this part of the report we will follow students within three of the development projects in a variety of settings. We will describe how they address the tasks presented to them in teaching, and how their knowledge is assessed by methods which are consistent with the inclusive policies of the programmes.

We will, however, start out by giving an overview of how the students themselves evaluate the programmes. How do they describe the problem-oriented, co-operative and interdisciplinary work forms, if we ask them about their attitudes towards such ways of working during their first year of study?

Introducing the Students' Perspective

The students' descriptions of the merits and limitations of the new ways of working are based on interviews with 26 students: 14 (out of 15) students at *The Project Programme* (two female and twelve male students) were interviewed at the end of their first study year (Scheja, 1996); Seven students (four female and three male students) in one study group at the programme for *Scientific Problem Solving* were interviewed at the end of the first term and a second time at the end of their first year on the programme (Wistedt, 1996b); Five students (four female and one male student) in one study group at *D++* were interviewed in connection with a group project in mathematics at the beginning of their first study year, three of them cited above. Their utterances, italicised in the text, have been translated into English by the author of this report, as have all the utterances that follow. The interviews lasted from 20 to 40 minutes; they were tape-recorded and later transcribed in full.

As mentioned in the introduction to this report, two notions summarised the pedagogical ideas as expressed by the teachers in the preparatory study – the notion of the self-directed learner and the notion of the social character of learning. Below we will describe how the students have understood these aspects of the programme policies as guiding assumptions for their studies.

The Self-Directed Learner

Most of the students interviewed seemed well aware of the fact that university studies in general, and problem-oriented studies in particular, call for an active student interest and participation in the learning activities:

> – *If you attend this programme you must have the will to co-operate. Otherwise you won't make it. You have to be set on co-operating when you work with projects. If you do not know how to do it beforehand you may eventually learn, but it is a pity if you think that studying is only a matter of running your own race. If you do not know how to work in a group, or lack the ability to learn, you shouldn't*

be here. You must at least have the will to learn, or strive in that direction. (Male student at the Project Programme)

In all of the three programmes the students have taken an active part in the development projects, especially the students enrolled during the first year many of whom are involved in various student activities within and outside of the programmes. In the two projects where the students are few (The Project Programme and the programme for Scientific Problem Solving) they have had ample opportunities to engage in discussions about the direction of the project. In some cases the students' influence on the policy-making processes have reached a point where the students tend to take over (Wistedt, 1996b, p. 43-44, Scheja, 1996, p. 43-45). Since the ways of working are new to most of the teachers involved, they too have had to learn how to make use of the new techniques. In the developmental process many questions arise for which the teachers do not have answers. If the teachers seem uncertain about the directions of the work, the students may rely on their own judgements when suggesting changes and improvements:

– You have to rely on yourself. I mean, you have to find things out for yourself, and see to it that things get done. Nobody will feed you with ready-made solutions. (Male student at the Project Programme)

Almost all of the students praised this strategy for promoting creativity and for giving the students latitude for own initiatives:

– You have to rely on your own thinking, and on the resources available in the group. (Male student at the programme for Scientific Problem Solving)

– You work independently which makes you more motivated. You do something that no one has done before. You are on your own, and you devote your time to subjects you have chosen. You have a great freedom of choice. (Male student at the Project Programme)

On the other hand, the possibilities for the students to be self-directed in their studies is not primarily a question about personal attitudes. The possibilities for the learners to take an active interest in their studies must be viewed in relation to the opportunities offered in teaching:

– Sometimes the tasks are too hard. If you have never heard of a topic before you have to ***invent it*** *all by yourself. Everything is brand new. Since lectures often lag behind in tempo, we are supposed to work with the stuff before the lectures. I don't think it works. Not always anyway. Some courses just aren't made for group work. Discrete mathematics, for instance. We should have had more lectures on that. You simply can't cope without them.* (Female student at D++)

– I don't propose that we should just have lectures. Not at all. One or two more perhaps, and an introductory lecture in which the most essential matters are

explained. Now we even have to figure out the fundamentals and the question is whether we wouldn't understand more if we had them explained to us, or something in that direction. It feels as if we need a bit more of filling things out before we get started. (Male student at D++)

The Social Character of Learning

Studying is, in part, a socialisation into disciplinary cultures. Within specific 'communities of practice' (Burton, 1995), for instance the practices of developing and communicating professional knowledge in engineering, certain ways of approaching phenomena are cultivated as are specialised means for communicating experiences (Wistedt, et al, 1997). Learning can be viewed as a process of getting acquainted with such specialised practices – a process of developing professional expertise.

Obviously the students, as new-comers to such communities of practices, cannot be expected to have the knowledge of all the conventions that constitute what counts as knowing within a subject area: which modes of analyses are appropriate in specific problem situations or what criteria of excellence are preferred. The students need tutoring by expert members of the community in order to develop an understanding of the course content which is regarded by these experts as relevant to the subjects studied.

The Need to be Supervised

The students seemed to be aware of this need to be supervised, and when they complained in the interviews about the ways of working they directed their complaints towards the lack of guidance from their teachers:

– Last term it did not work very well. The supervisors had been given the instructions to refrain from guiding us. This is what they had been told. But placing people in a group and not giving them any support at all doesn't work. As a consequence the reports were, on the whole, of low quality, as I see it. Two groups had real problems. Maybe some of the drop-outs resulted from this lack of guidance." (Student at the Project Programme)

As newcomers to the programmes the students may find it hard to define what aspects of a task are relevant to the subject studied and what aspects are of minor importance?

– The crucial task for the supervisor, which our supervisor failed to fulfil, is to help the students define the problem. We had taken it upon ourselves to express in mathematical formulas everything alive in the Universe. An impossible task, of

course. We should have restricted our ambitions to the description of worms, or something like that. That would have been enough. But we strayed. Our project became far too big. Our tutor suggested discreetly that perhaps we should cut down. Yes, we said and removed, like, the frogs. (Student at the Project Programme)

– Even if a task seems unambiguously phrased someone in the group always asks the question: But what do they actually mean by this? Are we supposed to answer the question in this way or that way? We haven't the slightest idea! We must try to figure it out. Last time they meant ***this*** *when they used* ***that*** *kind of phrasing. Maybe this is what they have in mind now.* (Student at D++)

The Risk of Developing Shallow Knowledge

If the guidance is weak the students may develop a sense of uncertainty about the quality of their learning. The students did not want the teachers to lower their standards. Quite the contrary – most of them asked for more stringency in the teachers' assessments of their work:

– I would want them simply to demand more of our results. If they say: 'Well, this looks good', I´m not satisfied at all. In one project I used the concept of standard deviation, but I was a bit uncertain about what it meant. I knew how to use it, I knew what it was, but I would have liked to develop a deeper knowledge of it. We used it in our project; our report says that the standard deviation is this or that, but I lack deeper understanding of the context of the concept. There you have the difference between six credits on a project and six credits on a course. Had I attended a six-credit course in statistics I'm convinced that I would have learnt more. There is a risk that the projects lead to shallow knowledge. We receive a lot of credits but learn nothing. I'm dead scared that the projects will be regarded as having low status. This is the feeling I have. Of course it isn't quite as bad as that, but in my opinion we run the risk of developing shallow knowledge. That is why I want the teachers to put more pressure on us. (Student at the Project Programme)

When the students expressed positive attitudes towards ”pressure” they spoke about it in qualitative terms. All of the students interviewed wished to develop a thorough understanding of the subject matter and they wanted their teachers to be observant to the qualitative aspects of their students' learning. In their argumentation the students pointed to the fact that thorough knowledge is needed in further education and sought after on the labour market; In addition it is a guarantee that the programmes will not be viewed as inferior to traditional programmes offered within the universities.

The Heavy Work Load

When the students talked about the quantitative aspect of 'pressure' they were, however, less positive. Most of the students complained about the heavy work load put upon them within the programmes, a problem which they referred to as caused by bad organisation:

> – *The organisation and the timetabling have not been entirely satisfactory, I think. Especially not the situation where a mathematics course and a physics course ran parallel during the second term; that was not particularly smart. It lead to failure in both subjects. When you study for a math test you tend to give priority to mathematics and cut classes in physics, which means that you get bad results in physics as well. And the projects got jammed somewhere in-between. A total disaster!* (Male student at the Project Programme)

At the programme for Scientific Problem Solving many of the students mentioned the heavy work load in the interviews carried out at the end of the first term. Some of them said that the teachers probably had had difficulty in foreseeing how time-consuming projects can be. If we consider that most of the students also found it difficult to define the aims of their work and the levels of ambition, maybe their engagement in the group projects was greater than was expected of them. We may also suspect that the teachers were quite eager to test their ideas for the programmes during the first year. In their ambitions to make the programmes challenging and interesting they may have been tempted to test too many new ideas at one time. This could well result in a situation such as the one described by the students.

Many of the problems mentioned by the students may be viewed as implementation problems. In the interviews with the students at the programme for Scientific Problem Solving, which were carried out at the end of the first year, the students seemed more relaxed. They reported that the tasks had been easier to handle, and they had had more time to devote to individual studies.

Evaluating the Learning Outcomes

Changing the approaches to teaching and learning is not an easy task. It takes time to implement new ideas and to try them out in real life situations. As the teacher at the University of Karlstad said: *The step is surprisingly big when you move from traditional teaching methods to student-oriented ways of teaching* (Renström, 1997). Making mistakes is a necessary part of developmental work.

We must also bear in mind that most of the students had a limited experience of university studies at the time we interviewed them. Category B students are relatively few within the programmes (see page 30 above). When the students commented on the heavy work load put upon them and the risk of developing shallow knowledge they may have been addressing matters that concern all university students:

> *– I think that many students believed that this would be an easy-going programme. Certainly it's fun, but it is also a lot of hard work and it takes a lot of time. I believe that some students thought that they would not have to study as hard. /…/ I was used to a high tempo from my previous university studies and I was surprised by the attitudes of some students. Many of the drop-outs didn't succeed on course examinations. I think that they had not expected that the pressure would be much higher at the university than at the upper-secondary school, maybe even higher within this programme since it is brand new.* (Category B student at the Project Programme)

Even if the attitudes expressed by the students are based on limited experiences of university studies, they are nevertheless interesting and important. The programmes were designed to raise the quality of student learning. The policy planners' arguments for the move towards more problem-oriented approaches to teaching was that the experience of such approaches would help the students develop an awareness of what learning and understanding in the respective disciplines consist of – to help them develop a professional or scientific attitude towards the subject fields (Wistedt, 1996, pp. 61-63). If the students nevertheless feel that they tend to develop shallow knowledge of the subjects, despite of the changes in approaches to teaching, we are faced with a problem.

On the other hand, evaluating the outcomes of learning is not primarily a matter for the students. Above we mentioned that if the guidance is weak, the students will have to rely on their own standards of evaluation. The students' questions about the quality of their understanding may be interpreted as an expression of a lack of confidence in their teachers' judgements and concerns: What if the teachers are so set on changing their teaching methods that they tend to overlook flaws in student competence? *(If they say: 'Well, this looks good', I'm not satisfied at all.)* What if they have been seduced by pedagogical trends? (*The supervisors had been given the instructions to refrain from guiding. This is what they had been told.).* Do they actually know what they have started, or are they so focused on changing the *forms* of teaching that they tend to disregard the question of what motivated the changes in the first place?

Evaluating student knowledge is the responsibility of the educators. Only experienced members of the professional communities can answer the questions that the students are posing – Is my knowledge valid? Is it comparable to what is expected of other students attending traditional university courses? Only trained members of a community can give an adequate answer to such questions.

Hence we cannot rest with the students' opinions about the programmes. We must ask the teachers for their evaluations, and since these teachers may be biased by their hopes and expectations, we must also ask other experienced members of the respective communities how they view the qualities of learning developed by the students.

If we want to involve people in a dialogue about the quality of student learning within the programmes we need to serve them examples of situations where such learning takes place. We need to supply *thick descriptions* (Geertz, 1973) of learning activities which could be commented on by people who have the expertise needed to evaluate various aspects of the students' knowledge. In the following chapters we provide such examples: in-depth descriptions of situations where students carry out tasks presented to them in teaching. In these chapters we will open a dialogue between people with different backgrounds who have been asked to reflect upon these pedagogical situations and upon the qualities of learning developed within them.

Mathematical Problem Solving in Computer Science and Engineering

At the end of October 1996, the first-year students at the Computer Science and Engineering Programme at Chalmers University of Technology (D++) took an examination following a course in logic and discrete mathematics. In groups of eight the students had devoted some weeks to studying mathematical concepts of importance to future programmers.
The examination consisted of seven tasks. One of them confronted the students with a proof:

a) What is wrong with the following proof?
Proposition: A relation R which is symmetric and transitive is also reflexive.
Proof: Suppose that xRy holds. Then we also have yRx since R is symmetric. On account of the transitivity xRy and yRx together imply xRx, that is, R is reflexive.

If you cannot find the fault in the proof you will receive two points for finding a counter-example to the assertion put forward in the proposition. (If you find a counter-example, maybe you should look at the proposition again and see why it does not hold up to your example.)

b) Let S be a relation on a set M such that S is symmetric and transitive and such that for every $x \in M$ there is a $y \in M$ such that xSy holds.
Must S be an equivalence relation? Give your reasons.

Five days after the examination we asked the students in four of the study groups at D++ (below called groups A, B, C and D) if they were willing to discuss their solutions to the task with their peers. Since we were interested in the collaborative forms of work implemented within the programme, we were eager to see how they functioned in the students' development of a deeper understanding of the task content. The students had not yet received their test results, but the teachers and the researchers knew that many of the students had failed to find the fault in the proof (only 17 students out of the

88 who had presented solutions to the task had received three points or more of the maximum six points awarded for a correct solution). Would these students succeed when they were given the opportunity to solve the task in co-operation with others?

Documenting the Students' Discussions

The group-discussions, which lasted for about 30 to 50 minutes were tape-recorded and later transcribed in full. Below we present the contents of these discussions in the form of descriptive narratives which provide information not only on what is said but also the details of the unfolding discussions, such as turn-taking and prosody (unconventionally stressed words are marked by extra bold type).

In order to depict the spoken discourse, direct quotations from the transcripts (*italicised in the text*) are linked together by interspersed comments. These comments are in most cases redundant (e.g. ”Eric said”), but in some cases they report observations which are lost in a verbatim transcription, for instance tones of voice. In some cases they introduce interpretations that are close to data (e.g. ”Lottie said encouragingly”). We do, however, strive to keep the interpretations to a minimum since we want the readers of the narratives to be able to contextualise the events in their own ways, and to feel free to ascribe meaning to the students' conversations from their own frames of reference. Our aim is to provide a descriptive basis for an evaluation of the co-operative and problem-oriented work forms implemented within the programme – to open a dialogue between teachers and other interested parties about these work forms as means for the students to develop their understanding of the concepts brought to the fore by the task.

One of the narratives is described in full below. It is presented in order to render a picture of the events which at least to some extent will enable the reader to take part in the dialogue about the programme policy. From the other three group discussions we provide short excerpts from the narratives. These excerpts are presented in order to give the reader a sense of the richness of the data and of the variation revealed by the students in their ways of handling the task.

The Group Discussions

Group A consisted of eight students who all volunteered to take part in the study: three female students: Julie, Lottie and Tina, and five male students: Bo, Eric, Martin, Nick, and Erwin (the names are fictitious). The observer informed the students about the aims of the investigation, put onto the table two tape-recorders which would document the students' discussion, and left the room.

Group A

Tell me what you thought

Eric started the discussion by turning to Erwin:

– *Tell me what you thought, Erwin, so that I know if I have solved this task the right way. If so, I can start arguing. Otherwise I don't know if I dare to.*

– *No, Eric. Tell us how you figured it out*, said Lottie.

– *No, I don't dare to*, said Eric.

– *Yes, tell us*, Lottie repeated.

– *Well, okay*, said Eric. . . . *eh*. . . *let's see how I did this*. . . , he hesitated. There was a short pause.

– *I can tell you how* ***I*** *thought*, said Lottie. *I didn't think at all*, she said and giggled, *because I thought that the proof was quite excellent. But, since they asked I understood that something had to be wrong. But I couldn't find the fault. I had no counter example.*

Julie agreed:

– *I also thought that something had to be wrong. You have to have a third element, that's what I thought*, she said and Lottie and Eric both agreed. *You have to prove the proposition for all y's, and you haven't proven it for all*, she concluded and turned to Erwin. *Now you may say something. What did you think?*

Here comes the key

– *Now we will learn how it should be*, said Lottie.

– *Here comes the key*, added Eric.

– *No*, said Erwin in reply. *But, I started out by devising the counter example*.

– *So did I*, said Julie and Eric in chorus.

– *And then I drew up a matrix*, Erwin went on.

– *A matrix?* Eric sounded quite surprised by this suggestion.

Erwin drew a matrix on the blackboard.

$$
\begin{array}{cc|cccc|}
 & & & y & & \\
 & & 1 & 2 & 3 & 4 \\
\hline
 & 1 & 1 & 1 & 0 & 1 \\
X & 2 & 1 & 1 & 0 & 1 \\
 & 3 & 0 & 0 & 0 & 0 \\
 & 4 & 1 & 1 & 0 & 1 \\
\hline
\end{array}
$$

Figure 5: The matrix provided by Erwin

– *This one fills the requirements*, he said, *that it should be symmetric and transitive. This one is.*
– *How do you see that?* asked Lottie.
– *I don't really know*, answered Erwin. *But it is anyway,* he added in a voice filled with confidence. *I sat very long with this one*, he explained.
But you cannot just **see** the transitivity, Julie objected. In order to assure yourself you have to *raise it to the second*, she said and Erwin agreed.

This is what I thought was wrong
– *But I thought that if you prove xRy and yRx you prove the same thing. I thought that transitivity meant that you needed to prove xRy and yR**z**, that you needed to prove that it followed from a **third,*** said Julie.
Lottie agreed and so did Tina:
– *Yes, that's what I thought too*.
– *That's what I thought was wrong*, Julie continued. *And then I designed a counter example.*
– *I used the example of the brothers and sisters*, said Eric.
– *So did I*, said Julie merrily. *And you cannot be your own sister. Exactly. I used that one too. It turned out fine.*
– *That will surely get us points*, said Eric.
– *Sure it will*, agreed Julie.

But what about the second sub-task?
But the suggested solution seemed to make the question posed in sub-task b) a bit odd:
– *Because you have already proven that the relation does not have to be reflexive, so it doesn't have to be an equivalence relation. It sounded quite ridiculous*, said Julie and Tina agreed:
– *Exactly.*
– *I also thought that the question was odd*, said Lottie, *because it seemed almost obvious. If we haven't made a mistake, of course*, she added. *But I thought that the task was hard to solve, because we haven't discussed this before, have we?*
– *No, but you know all the requirements for something to be an equivalence relation*, objected Julie.

How did the others think?
– *Now we want to hear Nick's lovely voice*, said Eric.
– *Yes, what do you have to say?* wondered Lottie.
– *Shit,* said Nick, *I didn't think.*
And what about Bo?
– *I thought that the proof was valid*, he said.
– *Yes,* agreed Martin, *at the beginning I thought so too. But when I looked at it again it turned out just as you have said: if you assume that x is related to y this implies that y is related to x. You just assume it.*
– *Yes, then that must be the fault,* said Lottie, *that you assume something which you have not proven.*
– *And you haven't proven it for **all** either*, added Julie, *because now you use both y and x, and reflexivity says xRx for **all** x. If this y had been an x,* she said and giggled, *we haven't proven it for that case. But then again…I thought that there had to be a third element involved. Transitivity says xRy and yR**z**.*

I don't really understand your solution, Erwin

– *But I don't really understand how you did this, Erwin*, Julie continued. *Can you explain these proofs once again?*
– *You haven't proven that it holds for all x*, Erwin explained, *and it must hold for all x, That's where I think the problem lies.*
– *Yes,* said Julie. *Isn't that exactly what I have been trying to say. And then the answer to sub-task b) is just a simple: No. I thought it was obvious*, she concluded, and Erwin agreed:
– *Yes, because in sub-task b) they have added what is left out in sub-task a): that* ***there exists*** *a y for every x.*
– *Well, I don't know…* said Julie slowly.
– *Neither do I*, said Tina.
– *All of us know nothing, except Erwin*, added Lottie.
– *You haven't proven it for all x*, said Julie. *That must be the answer. But then again, you don't know.*

But Erwin…I'm a bit curious about your solution

– *But Erwin*, said Julie, *you don't know how you did it, do you? I´m a bit curious about your solution.*
– *You did it with a matrix and a counter example*, Tina summed up.
– *And what does this matrix say?* asked Julie.
– *Well*, said Erwin and started anew, *this one is both symmetric and transitive*.
– *How do you know that?* asked Julie.
– *It doesn't look symmetric to me*, Eric objected.
– *Yes, if I look at it I can see that it is*, Erwin insisted.
– *What? You just check it out, and tell us that it is*, said Julie. *Transitivity doesn't just show.*
– *Yes,* Erwin insisted.
– *No it doesn't*, objected Julie. *I thought that there should be ones throughout the diagonal.*
– *No there doesn't have to be*, Erwin replied.
– *I don't think the diagonal matters*, said Lottie.
– *It doesn't?* said Julie in a bewildered voice.
– *It is reflexive?* asked Eric.
– *No, it is* ***not*** *reflexive*, answered Erwin.
– *But you cannot just say that it is transitive*, Julie insisted.
– *But it is*, said Erwin.
– *Well, well*, said Julie. *Give your reasons: Because it is. You can't just say it.*
– *It's better anyway than in some of the other groups*, said Lottie, *where you are not allowed to look at the others' solutions*.
The group members diverged from the task. Small talk commenced. Julie suggested that they should shut off the tape-recorder, since they seemed to have reached the end of their discussion, and so they did.

Erwin is the only member of the group who received the maximum six points for his solution to task six. The other group members did not know that at the time, but nevertheless they all seemed convinced that Erwin knew the correct solution. They did, however, have problems in following his argumentation, and Erwin himself had problems explaining his line of reasoning to the others. He just **knew** that his solution was correct, he provided the group with an example, but neither he nor the others succeeded in using it as a counter example. Julie, for instance, seemed to cling to her own interpretation of the task, and when she listened to Erwin explaining his way of thinking, she quickly assimilated his words to her own frame of reference (*Isn't that exactly what I have been trying to say?*).

If a student is to understand an explanation it must, in some way or another, be understandable within frames of reference available to the student. In another group (group B), the students used an example presented by one of the group members, and they managed to show why this example would not suffice as a counter example. They did, however, start out in low spirits. The students had just learnt that the results had been presented on the notice-board. None of them had received any points for their solutions to task six. The observer said that this could make the discussion rather interesting:

– *Interesting?* said one of the students, *I suppose we won't get anywhere as usual.* The observer left the room and the discussion started. Seven students participated, three male and four female students: Howard, Pug, Bob, Eve, Mary, Nadine and Carol. Nadine was not very happy with the teacher's verdict. She thought that her counter example served very well and could not understand why she had not been awarded any points for it. Since her examination had not yet been returned she tested her solution on the others.

Group B

– *Transitivity in fact involves three elements*, Nadine explained, *if x is related to y, and y to z, then x is related to z. That's what I thought.*
– *And here you only have two elements*, said Eve, and Mary agreed:
– *I wrote that too, but I didn't get any points for it, so it must be totally wrong.*
– *It doesn't have to be*, said Bob.
– *But what if z equals x?* suggested Herbert.
– *What?* asked Nadine.
– *If z is exactly the same as x,* repeated Herbert, *if x were to be equal to z the relation would still be reflexive.*
– *But I wrote that,* said Mary, *I wrote that x had to be unequal to z.*
Nadine started drawing a directed graph of her counter example on the blackboard:
– *I took the numbers 1, 2 and 3, and then I drew relations between them, such that 1 is related to 2, 2 to 3, 1 to 3, wait, there are supposed to be six. Well, since 1 is not related to 1, 2 not to 2, and 3 not to 3….But he* (the teacher) *didn't like it. I can discuss it with him, but…I'm totally convinced that this is a counter example,* she concluded and Bob and Mary agreed.
– *But what if x is equal to z*, Pug objected.
– *It is supposed to hold for* ***all*** *cases,* Herbert pointed out. *It's supposed to hold for* ***all****, isn't it?*
– *Yes*, said Mary in a voice that sounded as if she had just found something out.
– *So it doesn't help*, continued Herbert. *That must be where the fault lies. That must be it.*

– *Smart!* said Pug.
– *That must be it!* Mary exclaimed. *Okay. Maybe you have a point.That implies that x is related to x, but it doesn't imply that y is related to y.*
– *Yeah!* Pug agreed.
– *So it doesn't hold for all x.That must be it.Thank you Herbert!* said Mary. *That was great.Well, we have solved it.Thank you Herbert.*
– *I have just figured out that I will receive zero points on this task*, said Pug.
– *Yes*, said Mary, *but it feels good anyway that I was wrong. Or, it's a pity that I wasn't right and the teacher was wrong. It would have been fun. But,* she added a bit later, *why did you come up with the solution now, Herbert?*
– *I don't know,* said Herbert, *I never thought of drawing directed graphs at the exam.*
– *Well, you see*, said Mary, *group-work may help after all. Someone comes up with the idea of directed graphs, others tell you how to solve them,* she added and laughed*: Okay. Shared knowledge.*
– *Typical that this would be a case where it worked*, said Herbert and the others laughed heartily. *It hasn't worked before.*
– *Maybe that's because we have the examination behind us*, suggested Eve. *It has sort of loosened up a bit for most of us*, she added and shut the tape-recorder off.

The students in group B were interviewed a week later. In the previous chapter we presented some short excerpts from these interviews, in which the students commented on the forms of their work. Mary, Nadine and Eve also commented on their misunderstanding of the task in these interviews, for instance their conceptions of transitivity as involving three elements:

> – *It is very hard to understand that you don't need three elements*, Mary said, *"because if you look at the definition it says that x is related to y, and y is related to z, and then you draw the conclusion that there has to be an x, y and z involved, or I did, anyway*.

They also commented on the group work which this time seemed to have worked. Co-operation may be rewarding:

> – *Above all, other people may introduce ideas which you have not thought of yourself*, Herbert said. *It often works that way. You feel as if you get stuck on your own ideas. Others may get stuck as well, but they are captives of other ideas. But sometimes, we all get stuck, and in such instances the group work is a mere waste of time. That's when the 'I-will-do-this-at home' thought pops up in your head*.

In group B the students co-operated in finding a solution to the task. Even if they did not reach a satisfactory solution, at least they found out what was wrong with the counter example suggested by Nadine. In other groups, however, the group work did not involve all of the students. In group C, for instance, the students started out by asking each other who had tried to solve the task on the examination. Group C consisted of six students, five male and one female student: Carl, John, Tom, Calvin, Robert, and Emma. Calvin and Robert didn't remember, but Emma said that she had tried a solution and so said Carl. John and Tom were sure that they had solved it. However, Tom was the only one of the students present who received any points for his solution: three out of the maximum six points.

Group C

– *Since John and I already have ideas about this, maybe we should give those of you who are a bit uncertain some time to reflect upon the task*, suggested Tom.
– *No*, protested Carl. *Because I don't think that will mirror how we work within this group. That would be all lies. Because in our group we usually let those who really know something explain to those who don't.*
– *Precisely*, Emma agreed.
– *You just have to accept that*, Carl went on, *and I think that this should be documented.*
The group members agreed on this, and Tom started to explain what might be wrong with the proof. He drew a directed graph on the blackboard and started explaining. All points on the graph do not need to relate to the others in order for the relation to be transitive, he said. One conceivable case is where x is not related to any of the other elements:
– *What I'm trying to say is that it does not* ***have to*** *relate. That is what he does not prove, and that is why the proof does not hold,* he explained. *This proof holds if x is related to…there is supposed to be an* ***if*** *inserted there. And furthermore it is transitive, and there should be an* ***if*** *there too.* ***Then*** *xRy and yRx are supposed to imply…but what if x isn't related to y? x is standing somewhere all by itself. It doesn't relate. Nothing relates to it. That makes it all clear.*
– *But is it symmetric if it doesn't relate to itself…or, I mean, is it transitive?* asked Calvin.
– *Yes*, answered Tom. *But nothing points to it. You cannot get anything to point to it. It just stands there. That's what I thought, but…*
– *But I wonder*, said Emma, *doesn't transitivity mean that y is related to something else?*
– *Yes*, Tom continued, *the question is if a relation may include an x which is not related to anything. I don't know if that's allowed. But that was what I thought anyway.*
– *I absolutely think that it may*, said John. *Of course it may. The only thing you state is that a relation which is symmetric and transitive is also reflexive.*
But Tom was a bit unsure about his solution. When he read sub-task b), however, he became quite certain:
– *Oh, yes! Yes, this is exactly what they say here. Well, maybe you would like to reflect upon it for yourselves.*
– *No*, said Robert, *do tell us.*
– *Here they state that for every x within the set M it holds that x has to relate to y,* said Tom.
– *Are we satisfied then?* asked Robert and the others agreed. *In which case we desperately search for the off button*, he said and terminated the discussion.

In the fourth group, group D, there was some disquietude. Two of the group members arrived when the observer had already informed the others about the investigation. The other students told them about the recording:

– *We are supposed to fail in solving task six all over again*, said one of them.

– *From the exam*, another student filled in.

– *We have just volunteered to be evaluated,* a third student informed the newcomers.

Group D

Two of the male students placed themselves in front of the computer and started logging in. The other six, three male and three female students, started working on the task. One of the female students, Louise, was having a short conversation with two of the boys, Len and Curt, about the results of the exam which by now were posted on the notice board downstairs. Another female student, Vera, cut in:

– *I just want to remind you that this conversation is tape-recorded*, she said*, and you just sit there talking a lot of shit.*

– *They are recording us right now?* said one of the male students and silence followed.

– *It says here*, Vera continued and cited the text: *A relation R which is symmetric and transitive is also reflexive. That means that **if** it is symmetric and transitive it is also reflexive. And then they have presented a proof and that proof is wrong.*

The two boys at the computer and a third boy who had now joined them lead their own conversation in the background. Curt was sitting somewhere in-between the two groups trying to pay attentions to both conversations. Vera continued:

– *You could easily design a counter proof to this. You will just have to think about the definition of reflexivity.*

– *The mess on the screen is an error message*, Curt said to the boys at the computer.

– *Everything is recorded*, Vera reminded him, *and all of you just start messing around.*

– *Well, that is how things work in this group*, said Louise. *Someone is always occupied by peculiarities.*

– *Let's do this as we usually do it*, said Curt, *as we do it in our group. We idle away and get nothing done the first five weeks, and then we get into a state of anxiety the last two weeks.*

– *No, that is not **at all** how we do it!* protested Vera.

– *No, usually we search for the teacher*, said Louise. *No, let's say that four of us work hard while the others spend their time in front of the computer.*

– *Yes, and that is a pity*, another female students filled in, *because then only some contribute to the discussions.*

Despite the stir, Vera went on explaining her counter example to the others. When she had repeated her example a couple of times, Curt interrupted her:

– *You don't have to repeat what you say twenty times*, he said.

– *But I'm just trying to explain this to Len,* Vera told him.

– *And I need to hear it many times,* said Len, *since I'm not that clever.*

At the end of the discussion, five of the students participated in the discussion. Curt helped Vera in explaining the proof to Len who eventually accepted their arguments:

– *Because if x is related to y, for **all** x, it holds*, he said.

– *And hence the relation must be an equivalence relation*, Curt concluded and Vera agreed:

– *Happy, happy*.

– *Oh, joy*, said Curt and the students stopped the recording.

Dialogue

Before we open the dialogue it is important to remind the reader that the students are new-comers to the programme. They have spent less than two months at Chalmers and we cannot expect them to be experienced in solving mathematical problems. We may, nevertheless, use the narratives as a basis for reflection upon the programme policy. As mentioned in the introduction, this is not an evaluation conducted in order to sum up the results of the Government's initiative, but a study which invites people to reflect upon qualities of learning and teaching expressed in the midst of a developmental process.

Four teachers at Chalmers were asked to comment on the narratives: two mathematicians who were both involved in the Discrete Mathematics course as lecturers or supervisors to the students (below called Mathematician A and B), and two computer scientists both involved in the overall planning of the programme (called Computer Scientist A and B below). All four were interviewed in April 1997, that is six months after the group discussions took place. The two mathematicians had, however, received copies of the narratives much earlier, in November 1996. In preparing for the interviews they read these narratives anew. The comments from the four teachers are cited from the transcripts of the individual interviews and translated into English by the author of this report. Below their comments are brought together in a dialogue touching on three themes (in some cases the author has inserted short comments, which are bracketed in the text):

1. The students' understanding of the task and the concepts involved in it.
2. The students' understanding of the situation, that is, the collaborative work form and the problem-solving approach, and finally
3. The students' understanding of the cultural setting, which means that the dialogue will touch upon questions of how the students view mathematics as an academic subject situated within the culture of Chalmers University of Technology and, more specifically, within the Computer Science and Engineering Programme and the project D++.

The Students' Conceptual Understanding

The interviews all started with an inventory of the teachers' first impressions. What struck them on reading the narratives?

The Students' Lack of Contextual Knowledge

Mathematician A: *The first thing that struck me was how chaotic the learning activities seemed. I knew this already, but it was a bit tough to see anyway. Some groups managed to structure their discussions but certainly not all. This is, of course, just at the beginning of the programme, but do we really help them to find their ways out if it? I'm not sure that we do.*

Mathematician B: *Well, when I read these narratives the first time…I read them before as you know…my reactions were quite strong. I found the students' lack of understanding remarkable. When I read them now, about three weeks ago, I suddenly found this lack of understanding quite natural and something that could be expected. Then I started to think: Why do I react differently this time? And the only explanation I can come up with, which of course may be wrong, is that when you are in the midst of teaching a course you are absorbed by what you do: you constantly toss and turn the problems in your head, in fact you know them by heart. Everything is crystal clear. You don't have to think at all. When you are in such a state, it is very hard to understand why this would cause such problems for the students.*

But from a distance it is easier to see. I can see that they are in the same situation that I am in when I do my research. In research you often wrestle with things which you eventually will view as completely trivial, but at the time they seem far from obvious.

The students lack contextual knowledge. They have to create these contexts for themselves and they have to develop a feeling for the subject. In order to understand the problem fully, they must be able to formulate it in their own words. That is what every mathematician has to do, and that makes it easier for me to understand why learning is so hard for them.

Computer Scientist A: *One thing which I find very striking is that if you read the task that the students have received you will find that it requires an understanding of mathematical culture. For a professional mathematician it is quite clear what the text* ***means****. What is wrong with the proof? But in order to be able to answer that question you must have an answer to the question: What is a proof? The students have learnt about proofs by studying a number of proofs marked 'Passed'. These are accepted proofs. They are okay. It has never been made clear to them, I believe,* ***why*** *they are okay, not explicitly anyway. So it must be very hard for the students to know exactly where to look for the flaw in this proof.*

It is as if you have seen a lot of chess-games and from these games you are supposed to draw conclusions about the rules of the game.

Mathematician B: *What a trained mathematician would do, faced with this task, is to return to the definition and put on those near-sighted spectacles: look exactly at what the definition says and check out whether it works; disregard everything else. This they cannot do. This course in particular deals a lot with the problem of understanding various definitions which may seem very strange to a beginner. And when I read these narratives I find that we probably have to help them a lot more to understand that they have to work on the subject matter by returning to the definitions,* ***analysing*** *the definitions, assuring themselves that they understand the definitions, so that they do not put things into them which are not there, which they have a tendency to do.*

The Missing Links Between Mathematics and Logic

Computer Scientist B: *The first thing that strikes me is that the students tend to give up. I find that very sad to see. Erwin, for instance, seems to have understood where the fault lies, but he cannot explain his thoughts to the others, and they don't take the chance to help him make himself clear. He has provided an example and if he had been encouraged to explain it a bit further,* ***all*** *of the students would have had the chance of gaining a deeper knowledge, even Erwin himself may have added something to his formal understanding of the task.*

The students do not know how to relate this problem to what they have learnt in logic. If it says that A implies B this doesn't mean that A is true! In one of the groups (group C) *they are almost there: if an element does not relate to anything, can the relation still be symmetric and transitive? But they never link this question to logic: if something holds, something else also holds, and this may be true even if the antecedent is untrue.*

Computer Scientist A: *There are three things that they don't understand, as I see it: First of all they cannot handle variables. They don't understand what a variable* ***is****. You can see it on obvious things such as when they think that if the definition mentions three* **names** (for example x, y and z) *they think that these names must stand for different* ***objects****.* (see for instance Julie, Eric and Lottie in group A, Nadine and others in group B). *The second thing is that they cannot handle hypothetical reasoning –* ***when*** *you may make assumptions and* ***why*** *you make assumptions. I can well understand why. In mathematics this is only made* *clear when inductive proofs are introduced and then it is stressed to an extent that makes students think that this is the* ***only*** *time we make use of assumptions. Thirdly they do not know of any explicit rules for constructing proofs. And given these three shortcomings it is exceedingly hard for them to find out what is wrong with this particular proof.*

The narratives allow the commentators to get a close look at their student's ways of solving the task: *"This is only one example, but I really think it provides a lot of information"*, Computer Scientist B said in the interview. Such opportunities to scrutinise the process of learning do not present themselves in ordinary teaching where learning activities quickly pass by. Who knows what we may have found out if we had documented some traditional teaching sessions in the same meticulous way? Documented dialogues can be quite revealing and they may be revisited over and over again which makes it possible for the teachers to analyse the accounts and to compare them to their previous experience of learning sessions and to their hopes for the D++ project.

In their comments on the narratives the teachers tend to focus on the problematic aspects of the students' understanding of the mathematical content. There may be several reasons for such an approach. The teachers are all involved in a developmental process, and in such a process you learn from your mistakes. To focus on the shortcomings of your investments is a natural attitude. At the early stages of a developmental process your hopes for a rapid change in the students' attitudes towards learning may be quite high, and the higher the hopes the deeper the disappointment if progress seems slow and hard to come by. One of the mathematicians, who had the opportunity to read the narratives twice, commented on his first impressions and found out that he may have overreacted to the students' lack of understanding of the task. Learning is also a developmental process, and we must remember that the students will spend another four years in the programme.

In the interviews the teachers were given the opportunity to reflect upon their hopes for the programme. They were asked if the descriptions of the students' discussions made them happy or sad, or if the narratives refuted or confirmed something that the teachers already knew.

The Reproductive Views of Learning

Computer Scientist A*: It doesn't confirm what I know, but I'm not surprised. It's sad because we had wished or hoped that the students would develop a deeper feeling for what a proof is. We* ***knew*** *that the old system did not lead to the an understanding of how proofs work: the system where we presented course material from a text-book, ready-made proofs which we never discussed. But in this project we had the intentions that the students would find things out by working on the problems. But here they do not seem to take their chances to discuss the principles of proofs, which means that they will not understand what a proof is anyway.*

Mathematician B: *One of the big problems that we wanted to do away with was the mechanical mode of learning often practised in upper-secondary school, where you just solve standardised problems. But we seem to have gone too far in telling them that they are supposed to pay attention to the ideas. We have done this because we think it is important for them to understand the ideas, to understand what mathematical thinking is all about. But we have definitely gone too far in making light of the mechanical side of learning. You also need to know how to solve standardised problems and this you can only accomplish by training. And they do not understand by themselves that they have to practise a lot. Even if we tell them that they have to, they do not spend nearly as much time practising as they should. And this is something that may escape mathematicians, since we ourselves are constantly busy calculating.*

We are faced with a conflict which we certainly will have to deal with, which doesn't make things easier: We cannot turn back. We cannot let go of what we have accomplished within the project. We want to leave the standardised problems behind, but we cannot do away with them altogether.

The Students' Understanding of the Situation

One characteristic of the five projects within the Government's initiative is the extensive use of collective forms of work. In the Council's letter of invitation to apply for funds for development projects the applicants were invited to consider the possibility of making use of problem-oriented teaching methods. There is no necessary relation between problem-orientation and co-operative work forms, but many of the teachers seem, nevertheless, to have interpreted the proposals as a quest for co-operative modes of teaching and learning:

Tendencies to Focus on the Forms of Teaching

Computer Scientist B: *When we started this programme the students spent a lot of time in the group rooms. In fact, they sat there most of the time and we never intended them to do that. They believed that the* ***forms*** *of teaching defined the programme and the D++. In the narratives you can see that such attitudes still exist among the students. I think we have to make it very clear to them that individual work is the foundation of their studies and the group to which they belong is a resource which can be used for different purposes: for the purpose of gaining insight into problems, for the purpose of exchanging ideas, gathering information, sharing the work, constructing something, and a range of other purposes.*

The students seem to have a limited understanding of their work. Even the teachers themselves may focus on the forms of teaching:

Computer Scientist B: *We have not told the teachers that they should make use of group work, but they nevertheless seem to have understood our message in that way, which is a bit of a mystery to me. Collective work forms have attracted a lot of interest. I think that it is good that some teachers want to try them, but as you can see from the narratives such work forms are very demanding.*

The Absent Dialogue

What motivated the use of the co-operative activities and how did the teachers view them when reading the narratives?

Mathematician B: *Ideally the students should reach an understanding which is in accordance with the views developed by mathematicians, who over the years have come up with good theories and good definitions. The hopes were that if the students came together, each of them with fragmentary knowledge, or fragmentary but good ideas, they would be able to synthesise their views.*

Mathematician A*:* *But there is no real dialogue in the groups. If you have an idea, someone else presents another idea, and you listen to it with half an ear, and you think: Now I've got it. The students do not make use of each other's ideas. They do not listen to them, it seems.*

They appear to be a bit restless. They are focused on the results. And if they are, they will not take the time to toss and turn the questions. In the group where three *boys are positioned in front of the computer this may be viewed as a strategy to maximise the use of time. The pace is too slow. Let's run two parallel races.*

In the same group, group D, Curt told Vera that she didn't have to repeat herself twenty times:

Mathematician B: *Maybe he doesn't realise that in order to find the right answer, you need to go over these matters a hundred times. That is precisely what he should do.*

Computer Scientist B: *In group B the students started out by saying that co-operation doesn't work, but in the end they found out that it really worked this time. I wish I had seen more of that. But I guess we have to expect a lot of frustration to appear. The students tackle difficult problems which they are supposed to turn over and over again. Frustration is sort of built into the method.*

The Importance of the Physical Setting

When the students worked on the examination task they sat in their group-rooms in a building specially designed for the Computer Science and Engineering Programme. The students spend much time in these group rooms. For some purposes they function superbly. For other purposes they may not be as well suited, for instance for the purpose of learning mathematics:

Mathematician A: *Very early on the programme I found three things troublesome: First of all it is bothersome that the students cannot see me all the time. When I'm gone they feel abandoned. The second thing is that they cannot see each other. If they were all to sit in the same room they could watch the others work and learn from it. Some of the groups work very well, while others do not function at all, and in addition they would have to be more concentrated and respectful towards each other if they were to share a bigger room with the other students. Thirdly we have the matter of the computers.*

The last comment was also brought up in the interviews with the students. Herbert in group B said that the computers often function as magnets: *"It is a bit risky to put computers in the group rooms. I mean, there you have the screen, the empty square urging you: "Log in! Log in! Subconscious message!"*

Computer Scientist B: *Maybe we should put a switch outside the door which turns the computers off. There is no reason for them to stand there flickering when they are not supposed to be used.*

On the whole teaching has to be flexibly organised to serve the specific purposes of learning:

Computer Scientist B: *Computer technicians talk about 'design-space' when they devise solutions to problems. On one dimension you may position yourself in various places: you can, for instance, choose to use many small and simple processors, or you can use few but powerful ones, and in other dimensions you may consider other variables, which means that you have a 'space of possibilities'. The situation can be viewed as the same when you confront educational problems. It is really exciting when you think about the many possibilities that exist.*

A crucial thing is the construction of suitable tasks:

Computer Scientist B*: That is the biggest challenge of all. Some tasks may be designed for the purpose of introducing students to a subject, tasks which invoke ideas and direct attention towards the meaning of the subject matter. I think that such tasks are rare to find. Often the students need to prepare themselves for the group discussions and the problem is that some do, some don't, and some do but still do not get the hang of it.*

Co-operative Work Forms and Female Students

The co-operative forms of work were implemented to serve the interests of female students. In all of the groups described in the narratives there were female students present. Did they seem to benefit from working in co-operation with others?

Mathematician A: *It is really fascinating to see how the women take up a great deal of space. It may sound negative, but I do not mean it that way. They pose the questions. The boys are more reluctant to do so. And I must say that the women are indispensable in the study groups. I don't know how we would manage without them. But then again, one of my tutorial groups, which functions the best, consists of boys only, so it is difficult to say what we have here. But you can see, for instance, that in group D the women are those who work the hardest. The boys are slacking off. Len, on the other hand, asks Vera all the time what he should do so it doesn't hold generally. Perhaps many boys believe that they have to be* *clever. They need more help than they want to admit. I know the type. I've seen a lot of them over the years, and it never ends well. I guess Curt is such a person: I know this already, but I still need to listen with half an ear.*

Computer Scientist B: *In group D the women seemed to take on a lot of responsibility. Not only did they want to solve the problem, they also wanted the others to take part, and they told the boys that if they did not contribute to the discussion their experiences were of no use to the group.*

I'm not at all sure that women in general prefer group work, but I think that women are needed in work groups. When I talk to representatives of companies they say that mixed work groups function the best. They hold together, and that is what you can see in these narratives. The women are needed in the groups. But maybe those who make the detours are needed as well.

The Students' Understanding of the Cultural Setting

Many of the students' attitudes, which are commented on in the dialogues above, can be subsumed under a more comprehensive description of their understanding of the content and the setting in which it is embedded – a view of learning often found among students in upper-secondary school, identified by pedagogues as the *reproductive mode of learning* (Marton & Säljö, 1976; Säljö, 1982; Marton, Hounsell & Entwistle, 1997): What characterises this mode of learning is the focus on the outcomes of learning rather than on the process of gaining insight, the compartmentalised view of the subject matter where links between different subject areas are not created since they are seldom needed in order to pass the exams, the individualistic turn, the heavy reliance on authorities, the tendencies to focus on the appearance of phenomena rather than on their meaning, such as the **forms** of teaching or the **wordings** of definitions and the like; all of these attributes of the students' approaches to learning belong to an epistemological tradition alien to a scientific mode of thinking.

The students are entering a new culture, and they bring to this new setting their previous learning experiences. Certainly we may expect cultural conflicts to appear. But these are not simply conflicts between the school culture and the university culture. Some of the students seem to have preconceived opinions about Chalmers University of Technology and what is expected from the students at Chalmers: they view studies at Chalmers as a prolongation of the studies at the upper-secondary school, just more demanding in quantitative terms.

The Computer Science and Engineering programme is, however, moving towards qualitatively new ways of viewing learning and instruction, which means that we also have to consider possible conflicts between the culture of Chalmers as perceived by the students, and the changing culture of the programme. As can be seen from the comments to the narratives, D++ is a development project in the true sense, which means that the students are not faced with a firmly settled conception of knowledge, but a many-faceted and interdisciplinary culture in the making.

The School Culture and the University Culture

Mathematician A: *I must tell you that I had a lot of sympathy for a woman in one of my tutorial groups. I guarantee that she would have passed all of the courses if they had been traditional courses. She knew exactly what to do if I told her what to do. But if the examples varied and new things were introduced she was at a loss. She needed prescriptions. And I thought: Poor you. Had this been a traditional course you would have made it. But she lacked the knowledge in a deeper sense and I had to accept that. But I must say that I felt sorry for her. She has left the programme by now.*

But if reproductive modes of learning do not suffice for the future engineers, is it not reasonable that the teachers do not encourage such approaches to learning? The strategies may have been successful in upper-secondary school, and up to now they may have paid off. Now they don't:

Mathematician A: *Yes, and that seems so horribly cruel. We demand something completely new of the students and we have done very little to explain what we expect from them. I believe that we have to put a lot more energy into getting them to understanding what our mission is. Two things compete here: the school culture which tells them to make their teachers happy and content, to pass the exams and the like, and the cultures of the subjects. Just to push them into these cultures is to fool them, I think. We believe that they will eventually understand the cultural demands, but at the same time we give them exams and exercises and tell them what they should have learnt.*

The Traditional View of the Chalmers Culture

All of the teachers commenting recognised the traditional view of learning described by Curt in group D:

Mathematician B: *He definitely described the Chalmers' cliché. Most of the courses have been designed that way for years. The major part of the mathematics* *courses anyway. The students have received lists of standard problems and exact prescriptions about what pages they are to read in the text-book, and there have even been lists of propositions which may appear on the examination, which the students are expected to be able to prove. If teaching is like that, the students can easily study in the ways described: you do nothing the first five weeks and then you cram like a madman the last two weeks. This has been the teaching model at Chalmers for a very long time and it doesn't work very well. Not if the students are supposed to learn.*

I believe that we have to help the students realise the merits of the co-operative work forms. We must introduce them as clear and present alternatives to the old macho-Chalmers image. I firmly believe that this would be of benefit to all students, but each year there will always be some groups which will need some extra help over the threshold in order to accept working in groups.

Computer Scientist A: *Yes, but my impression is that the traditional attitudes are less frequent now than they were before. I have tutored second-year students this term. The students were supposed to be prepared for the tutorials, they were expected to lead the discussions, and to introduce topics. I found that to be an idealised view. The students were not as well prepared as I had hoped which may be explained by the fact that three courses were running parallel in the programme. The students simply didn't have the time to prepare properly. But my impression is that their workload is more evenly distributed over the study periods now than before, which means that they definitely learn more.*

Cultural Differences Between Subjects

The narratives describe how students solve a task which appeared on a course examination in Discreet Mathematics. The mathematics department has responsibility for teaching and examining the students, but the course is also of great interest to the computer scientist:

Computer Scientist A: *On planning the programme we were very eager for this course to be realised, to appear early on the programme and to be placed parallel to our course. But I think that we did not succeed in describing to the mathematicians* ***why*** *we wanted it to be placed where it is. The concepts are, of course, of major importance, but it is equally important that the students understand the logical structure of an argument. It is very important to us that they know how to write down a proof in an explicit way. When you are programming and supposed to instruct a stupid computer you need to be* *extremely explicit. And furthermore, since programs often need to be extended and modified many times, perhaps by people who did not write the original program, they must be simple and systematically built in order to be possible to understand and modify. This means that it is important that programs are conceptually clear and properly modularised. Mathematics text-books often do not have that view of proofs. Proofs may be long-winded, they may take some extra turns on the route, and the mathematicians do not find that particularly upsetting.*

When proofs are presented in text-books the most simple cases are seldom discussed. They may not even be mentioned. The interesting and difficult cases are mentioned, while the simplest ones are regarded as obvious. Mathematics is a tradition with a long history. Proofs are often presented as ready-made products. But the details, how you get there, are not discussed. It may even be viewed as a sign of elegance that it doesn't show, which is odd.

Mathematician B: *One of the problems with mathematics is that we all have to understand things in our own ways, ways which still have to be in accordance with the common definitions. All of us interpret the common language in individual ways, and when you try to explain something to someone you will find that you really haven't used the common language as a tool of thought. The mathematical language serves as a communicative tool. No one* ***thinks*** *that way. We all have our own internal languages. And when you have reduced your thoughts to match the common language, all trained mathematicians will know exactly what you mean. They can translate it in their turn, they can see the picture and the structure.*

Computer Scientist A: *We have suggested that we should use a system of rules of inference which is systematically built: there are two rules for each connective: two rules for 'and', two rules for 'or' which follow exactly the same pattern, and which is complete in the sense that all tautologies have a proof within the system, and conversely, if you prove something within the system it is a tautology. So it's perfect. Those are the simple rules used in everyday reasoning. To us they stand to reason. Every thought of using another system at least has to be argued for. But the mathematician find it too complicated. In this system 'assumptions' are included since they are central parts of proofs. If you do not have a system which can handle assumptions, of course you can never capture how mathematicians make proofs! So that is an advantage to the system, not a disadvantage.*

But there exists a certain pecking order between disciplines. The mere thought that we, as computer scientists, have opinions about how to devise proofs, which may even be better than mathematicians' own, is, of course, an irritating thought.

Obviously, not all mathematician would agree with these views:

Mathematician B: *The narratives and my experiences from teaching this course tell me how difficult it is to learn, even chaotic at times. To believe that if we were only to present things in a rigorous way the problems would pass, is a bit naive. I believed this myself when I started to study mathematics, and I was depressed for many years that I never succeeded in gaining a complete view of the matters that I studied. It took me years to accept that I never will.*

The views of proofs may also vary between subjects. Proofs, which computer scientist find roundabout, may have their merits within a mathematical context. The detours may be essential parts of a mathematical interpretation of the proof. They may, for instance, help in clarifying the overall idea. But then again, computers are not interested in ideas:

Computer Scientist A: *You have to adapt your teaching to different groups of students: what they require of mathematics and what they can take. Our students are at the same time trained in using formal languages, and how you build such languages; they are trained in devising precise definitions which makes them more prepared to confront precise mathematical arguments: they need them and they will enjoy them more than other students may do. Sloppy argumentation will do them more harm than good.*

The mathematicians involved in this course are very interested in it and they have invested a lot of time and effort into it. They do not agree with me, but then again, I may be wrong. But as a supplement to computer science the course does not serve its purpose. When we planned the programme we hoped to be able to integrate the subjects, but integration has proven to be very hard to accomplish.

A Short Summary of the Outcomes

In the dialogue the commentators discussed problems which still remain to be solved within the Computer Science and Engineering Programme at Chalmers: They pointed out that some of the central goals of the programme

– such as the students' understanding of key concepts in mathematics, their ways of thinking in the discipline, and their development of abilities to integrate knowledge from different subject domains – have not yet been achieved. The sources of the problems were traced to the quality of the students' engagement with the instructional task and with the experiences offered by other students within the study groups. The students' approaches to learning still seemed to be coloured by their experiences from the upper-secondary school and in some cases also by their traditional views of what characterises learning at Chalmers.

What strikes a pedagogue, however, is the teachers' reflective stance towards the educational problems confronting them. As some of the students pointed out in the interviews, teachers may focus on the solutions to problems before they have analysed what characterises these problems in the first place. These teachers did not. Openly and critically they penetrated the educational task: they directed their attention towards qualitative aspects of their students' learning and towards the possibilities of setting favourable conditions for the development of more fruitful approaches to learning. Even if the teachers did not always agree on what should be done, they all seemed convinced that they had to come to grips with the problems facing them.

Mathematician B: *There is no going back. A sufficient number of teachers within our department have accepted the programme policy and are enthusiastic about it. We would all find it very hard to return to traditional methods of teaching. But these ways of teaching demand a lot of work. I have never put this much effort into any course that I ever taught before, and I would not like to have to do it year after year.*

Development work is demanding. The teachers within the D++ share their problems with the teachers in the other projects. In the following chapter we will continue the discussion about the qualities of learning developed by students on the programmes within the initiative. Before we do, however, we would like to remind the reader of the aim of this evaluation, which is not to praise or condemn the ideas expressed in the initiative, but to provide information which invites people to reflect upon the changes in approaches to teaching implemented to serve the needs of the learners, especially the needs of the female students recruited to the programmes:

"Evaluation is often viewed as a test of effectiveness – of materials, teaching methods, or whatnot – but this is the least important aspect of it. The most important is to provide intelligence on how to improve these things." (Bruner, 1966, p. 165)

Learning Mathematics in a Collaborative Setting

In the previous chapter we provided examples of how students carried out a mathematical task in collaboration with their peers. From the examples we learnt that the female students played an active role in the groups and contributed substantially to the group discussions. Two of the commentators also stressed the importance of their contributions, and pointed out that the female students were indispensable in the groups since they helped in keeping them together.

One may, however, object, that playing such a supportive role in a group is to take on an extra burden of responsibility. If women are inclined to play such roles in the study groups, the recruitment of female students may serve the interests of male students rather than the needs of the female students themselves. On the other hand, we also provided examples of situations where all members, male and female, contributed to and benefited from the collaboration. In one of the groups the students pointed out that the group work, much to their surprise, helped them in clarifying the issues brought into light by the given task. Even if they did not succeed in finding the fault of the proof, at least they managed to find the flaws in their own suggested solutions.

Collaboration in itself does not, however, guarantee success in problem solving. All of the commentators to the narratives presented in the previous chapter were well aware of the fact that students need help in order to co-operate efficiently: The tasks have to be designed in ways which promote reflection upon the subject matter, the organisation of the teaching must be flexible and adapted to the specific purposes of learning, and the teachers must not take it for granted that the students will understand the merits of the co-operative work forms and the essentials of the subjects all by themselves.

Below we will explore these issues a bit further by investigating how students from two of the other programmes within the initiative confront mathematical concepts in a collaborative setting. Six mixed-sex groups of three to five students each, three groups from the Project Programme at Stockholm University and three from the programme for Scientific Problem Solving at Göteborg University, were presented with a task which confronted them with a concept, known to be an obstacle to many undergraduate students – mathematical induction. All of the students were first-year students and all of them volunteered to take part in the study.

The Task

The task which we gave the students was unconventionally designed. Our hopes were that the non-traditional form of the task would prevent the students from viewing it as a routine problem solvable by standardised methods. Rather we wanted them to view it as a genuine problem promoting reflection upon the essentials of inductive proofs.

In traditional teaching, mathematical induction is usually taught on the basis of algebraic examples: a certain expression, such as a sum or a recursively defined sequence of numbers, is dependant on a positive integer n and the students are supposed to prove by induction that a certain proposition holds for the given expression[2]. The task presented below is not algebraic but geometrical: It concerns a puzzle whose dimensions are dependant on an integer n. The proposition that the students are supposed to prove by induction states that the puzzle is always possible to solve:

[2] A typical example would be the following:

Prove that

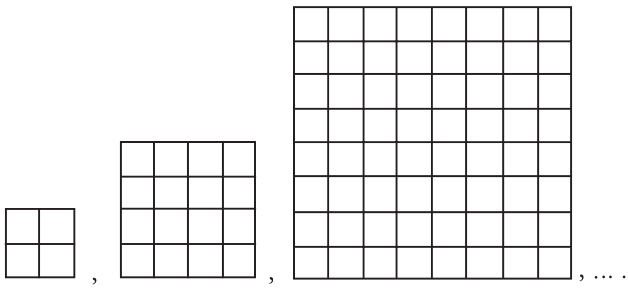
$$\sum_{k=1}^{n} k^2 = \frac{n}{6}(n+1)(2n+1)$$

for all integers $n \geq 1$

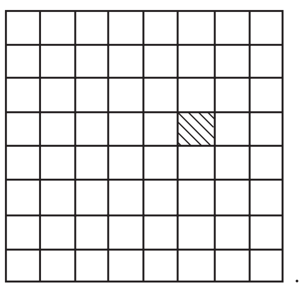
The proof involves a certain amount of algebraic manipulation of polynomials in n, and also requires a clear grasp of the use of the summation symbol Σ.

Defective Chessboards and Induction

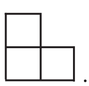
Consider a 'chessboard' with $2^n \times 2^n$ squares where $n \geq 1$. So for $n = 1,2,3,\ldots$ we have:



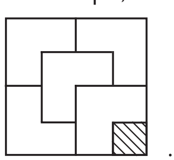
And so on. (Hence for $n = 3$ we have a 'genuine' chessboard.)
Now, let us remove one square somewhere on the chessboard. Like this for instance:



We call this a 'defective chessboard'. We shall try to cover a defective chessboard by L-shaped pieces:



For example, below is a covering of a defective $2^2 \times 2^2$ chessboard:



Problem: Using induction, show that it is always possible to cover a defective $2^n \times 2^n$ chessboard, for all $n \geq 1$ and regardless of where the square was removed from the board.

Figure 6: The task

The text states a problem, or at least that is what it says. But does it really? What we can see is a text which has to be interpreted. It does not 'contain' a problem ready to be solved, even if the intended interpretation may seem obvious to an informed reader.

When we talk about problem-solving approaches to learning, or problem-orientation on behalf of the students, we often presuppose that the students will direct their learning activities towards matters of relevance to the subjects studied – towards problems as they are defined within an academic culture. In the previous chapters, however, the students and teachers pointed out that such problems are not always easy to delimit by the learners. The students may stray, or they may lack the knowledge required to understand what is expected of them. This means that we cannot take it for granted that the students are oriented towards the specific problems that the teachers have in mind (Halldén, 1982; 1986; Wistedt, 1994a, 1994b). The act of defining a problem is an act of interpreting the information given in a text or a task within frames of reference available to the learners. So, let us turn to the students' interpretations of the task given above.

The Purposes of Learning

Methods of Analysis

How are we to know how the students interpret the task? The method of analysis used in this and the following chapter is based on the principles of **intentional analysis** (von Wright, 1971; Downes, 1984, pp. 266-364; Halldén, 1994; Wistedt, et al, 1997). On the basis of an extensive documentation of what the students say and do during a learning session we ascribe meaning to their utterances and activities in terms of intent – we view their actions **as** intentional, which means that we describe them in terms of some purpose of the actors in order to achieve a goal, a goal which will render their activities intelligible. We do not, however, claim that the students themselves understand their activities in the ways described.

In our everyday lives we usually ascribe meaning to the activities of our fellow beings since we believe them to be intentional agents. Acts, such as problem-solving, proving, hypothesising, and the like, are all descriptions of goal-oriented activities, intentional in nature. The difference between everyday descriptions of intentions and intentional analysis lies in the analytical approach. When we draw conclusions about the meaning of activities observed in everyday life, we usually rely on our background knowledge of what could be expected of people within a social setting. Many acts are, in fact, social institutions, for instance the act of proving a proposition within a mathematical community. However, since students are not officio members of their communities of academic practice, they may well carry out acts in unconventional ways. This means that we have to guard ourselves against ascribing meaning to their activities in preconceived ways. We may **not** draw the conclusion that students who sit in a group discussing a task are involved in 'problem-solving'. We have to assure ourselves by testing such an interpretation against single utterances and sequences of utterances in an on-going dialogue with the empirical material (for a more elaborate description of the specifics of such an analysis, see Downes, 1984, pp. 266-364). We have to identify acts by inference, and we have to make our inferences and the data on which they are based available for critical scrutiny. This means that the analysis must be based on careful documentation that reveals the meaning-making process. Below we present such data from one of the six groups who solved the geometrical task presented above. More extensive versions, including all six groups who addressed the task, have been presented elsewhere (Wistedt, et al, 1996, 1997).

A Group Discussion About Inductive Proofs

In one of the groups at the programme for Scientific Problem Solving five students worked together: Andy, Irene, Jacob, Louise, and Robert. They started out by updating what they remembered about induction and quickly moved on to the drawings in the text.

Defining the Problem

– *Look how nice this is*, said Louise, *how many squares do you need to cover a board? Each L-piece consist of three squares, which means that you have three times the number of squares, plus the extra square which is left over.*

– *And you can put that anywhere you want*, added Irene.

– *No, you certainly* ***can't***, objected Jacob. *It says here: Using induction, show that it is* ***always*** *possible to cover a defective chessboard, for all n,* ***regardless*** *of where the square was removed…*

– *Yes, precisely,* Andy agreed.

– *Yes,* said Louise, *that is what I mean. Regardless of where you put it, you can solve it.*

– *Yes, but that doesn't mean that you can choose any square you want and check if it works,* said Jacob.

– *But it is supposed to work regardless of where you put it,* said Louise.

– *Exactly,* Jacob concurred.

– *And by using induction you can choose,* Andy remarked. *You just make the assumption that this is what I choose.*

– *But it is supposed to work for any positioning of the defect,* objected Louise.
– *You choose one example, and at the same time you are supposed to prove that it works for all cases,* said Jacob. *That is the problem. Just proving that it works for a single case is a piece of cake.*
– *You could always prove that the number of squares is divisible by three,* said Louise.
– *Yes, that's easy,* said Jacob.

Checking the Solution

– *But look here*, said Andy and pointed to the 2 × 2 board. *Solving this one is trivial.*
The others agreed cheerfully: that would be an easy assignment.
– *So let's take this one and put it here,* said Andy and pointed to the 4 × 4 board. *We can take this one…*
– *No, wait a minute*, protested Louise. *We aren't supposed to have more than one defect.*
– *No. You're right,* Andy agreed. *That would be too many.*
– *That would give us four black squares,* said Irene. *But on the other hand, we would have three left.*
– *What? Three left?* asked Louise.
– *Those three,* said Irene and pointed to the drawing.
– *And you can place those anywhere you want,* said Andy.
– *And then you can put in an L to cover them,* Irene concluded.
– *Okay*, said Louise and made a drawing. *If we move this one* (the 4 × 4 board) *on to this one* (the 8 × 8 board) *we have covered them all. And you can enlarge it even further.*

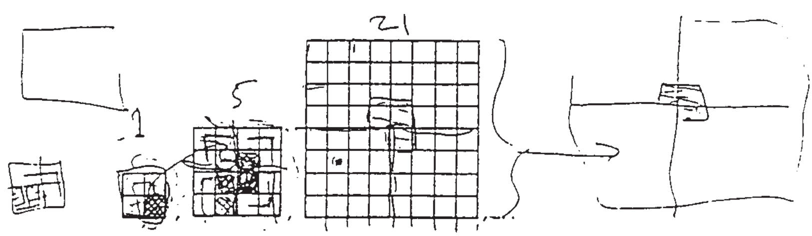


Figure 7: The geometrical sketches made by the students.

– *And then we're supposed to describe this mathematically*, said Louise giggling.
– *This is not a proof,* said Irene, *this is just a way of showing how it will turn out.*
– *Yes, now we've done it logically,* said Louise.
– *Now we know that it holds,* said Irene. *Now we believe in it.*

Proving the Proposition – The Algebraic Way

Louise wrote down a formula which showed that the number of squares in a defective chessboard is always divisible by three
– *But the only thing it says is that the number of squares add up,* she said and Robert agreed.
– *But we're not supposed to sit here just testing, are we?* said Irene. *It works for this one, and for this one, and…*
– *Let's strike out the first part of the sentence then,* suggested Louise and the group members laughed heartily.
– *You could always do it by induction,* said Andy. *But it wouldn't be mathematical induction,* he

added. *Is there any other way?* he wondered and silence followed. *Of course, you could always prove that it holds for the smallest board,* he suggested to the others.
– *Where n equals one*, said Irene.
– *Yes,* said Andy, *and then we raise it to two and show that it holds for that one too.*
– *No,* objected Louise, *the next step would be…*
– *…that you* ***assume*** *that it holds for…* Robert filled in.
– *…assume that it holds for k,* said Louise.
– *Yes, okay*, said Andy, ***that's*** *how you do it. Yes.*
– *And then for k+1,* Robert reminded him.
– *k+1, yeah, that's it,* agreed Andy.
– *The question is how you write it down,* said Andy and looked at Louise's formula.
– *This says nothing about the placement of the square,* she said, *it just tells you about the number of squares.*

Proving the Proposition – The Geometrical Way

The students found out that the L-piece could be placed in four different ways on the smallest board. Could that be helpful?
– *In order to cover this board* (2×2) *you need one L, but there* (on the 4×4 board) *you need five, whatever that means*, said Andy.
– *But I don't understand how we are to describe where on the board the defect should be placed,* said Irene.
– *No*, said Louise, *but if we do it like this…*
– *Is that mathematical induction?* asked Andy.
– *What the heck…induction*, said Louise with a laugh.
– *I think we have solved it,* said Andy. *By induction, almost.*
– *Yes, okay,* Louise agreed.
– *But the thing is*, objected Irene, *that induction is to prove something…*
– *…for k*, Andy filled in.
– *…and for the number of x,* continued Irene. *We have just tested.*
Jacob tried to formulate in words what the students had discovered:
– *Let's say that one out of four squares is covered. On the other three squares we place the holes so that they are available to all three. It's as simple as that. One is covered by the defect and on the other three we can choose where to place the holes. And then we see to it that the holes are placed so that they form…*
– *…an L-shape,* Andy filled in.
– *Yes, but the problem is how to write it down mathematically. That is incomprehensible. It is almost impossible,* Jacob said with a sigh.
– *Yes, but as we said: This is, after all, induction. Really,* Louise stated.
– *It is induction, although not mathematical,* said Andy and laughed.
– *But it doesn't say* ***mathematical*** *in the text,* said Louise. *It doesn't.*
– *No, you're right,* giggled Andy.
– *But it is induction,* Louise insisted. *We have shown that you can put it there.*
– *We have reasoned our way through the problem,* said Irene and finished the discussion.

The Collaborative Work Form

What characterises the collaboration between the students? Apart from Robert, who participated very little in the group discussion, all of the students took an active part in the exploration of the task. They willingly shared their views with each other and openly revealed what they did not know, as for instance when Andy confessed that he had forgotten the specifics of inductive proofs (*"Yes, okay,* ***that's*** *how you do it"*). The atmosphere was cheerful and easy-going and the students sometimes took the liberty of approaching the mathematical discourse in a playful way, for instance when the word 'trivial' popped up in the discussion, to the students' common amusement. The mathematically oriented reader will recognise the word as an expression often used and sometimes misused in mathematical conversation.

The students tried out a variety of interpretations of the task and they also argued against these interpretations. About one third of the total number of 247 utterances can be described as elaborations of contributions previously made by others – utterances, tentatively formed by one student, are reformulated or filled in by another student and completed by a third member of the group (for example p. 80 above).

The communication is clearly a case of co-operation, a communicative style often said to be preferred by women, in contrast to the adversarial style more often found in male conversations (e.g. Coates, 1993). On the other hand, the conversation sometimes took on an adversarial tone, for instance at the beginning of the period, when Jacob strongly objected to Irene's statement that the defect could be placed anywhere on the board. We found the same conversational pattern in the other five groups who solved the task: the students tended to make use of both styles of communication – the co-operative style and the adversarial style. We also found that an overuse of either style could lead to the overlooking of fruitful arguments (Wistedt, *et al*, 1996). In the group where the students did not succeed in finding a solution to the task the members seemed so keen on holding the group together by agreeing with each other that they missed the chances of elaborating the meaning of the utterances put forward in the discussion (*ibid*. p. 79-88).

The female students in the group above contributed a lot to the group discussion: Louise, for instance, assumed the major responsibility for illuminating the shortcomings of their argumentation by raising questions, challenging views, and clarifying the meaning of the other students' contributions to the discussion. The female students did not, however, take on the supportive role described by the teachers in the previous chapter – the role of holding the group together. They were supportive, in the sense that they built on, elaborated, or refuted the other students' utterances, but they were not mothering the other members. The group was rather held together by the students' common ambition to find a proof for the proposition stated in the task.

The communication described in the narrative above comes very close to the ideal of a collaborative learning session. This makes the example an ideal case for investigating the relationship between the forms of work and learning outcomes in terms of how the students understand the content of the task. To investigate such a relationship is one of the aims of this evaluation. Let us, therefore, turn to the students' understanding of the assignment and the concept of mathematical induction.

The Students' Interpretations of the Assignment

The assignment was designed to promote reflection upon mathematical induction. As expected, it caused consternation in all of the six groups. None of the students seemed to view geometrical proofs as acceptable within a mathematical culture. In all six groups who worked with this task, the students seemed to prefer algebraic interpretations of the task, and we may wonder why. It certainly came as a surprise to their teachers when they read the narratives. They never said that algebra was an essential characteristic of induction. They may have used algebraic examples in their teaching, but we all know that mathematics works much like judicial law – what is not strictly forbidden is allowed. Even if **all** examples used in teaching were to be algebraic, this would not mean that they have to be, unless such a requirement is explicitly stated.

But what about implicitly? Learning takes place in a social environment, and the students are sensitive to that environment. Students learn not only from what is said in teaching, but also from how knowledge is presented and valued (e.g. Marton, *et al*, 1997; Säljö, 1982; Perry, 1970). Many of the students in the previous chapter believed that transitivity involved three elements, since three names were used in the definition of the concept; the students in all of the six groups discussing induction believed that inductive proofs were algebraic in essence, a belief that probably follows in part from the fact that algebraic examples were used when the proof method was introduced in teaching. Professional mathematicians may well regard such details of presentation as form and background; the students, on the other hand, may easily come to view them as content and pattern.

If the students believed that algebra was an essential characteristic of mathematical induction, an algebraic interpretation of the assignment simply fit with their views of how to perform inductive proofs. But the task didn't seem to lend itself to algebraic manipulations. Viewed from an algebraic perspective the task seemed impossible to the students, almost inconceivable.

In the group discussed above, an alternative interpretation to the covering problem was offered – the problem of proving that the number of squares in a defective chessboard is always divisible by three, a problem which the students knew how to solve by algebraic methods. Louise, who suggested it to the group, realised, however, that this was not the problem intended by the author of the text. The proposition: that the number of squares in a defective chessboard is divisible by three, is a weaker claim than to state that a defective chessboard can be covered by L-pieces (*"This says nothing about the placement of the square, it just tells you about the number of squares"*). Nevertheless, in two of the groups at Stockholm University, and in all of the three groups at Göteborg University the divisibility problem was suggested by one or more of the students in the groups, and in three of these groups the problem was explored in great detail. The students all seemed hooked on algebra, a way of reasoning which they seemed to identify with **mathematical** argumentation.

Understanding Induction

In five of the six groups, however, a geometrical solution was eventually proposed and elaborated by the students, and in all of these groups the students appreciated the solution which they did not only find convincing, but *"damn neat"*, even *"beautiful"*. The students were not, however, able to devise a method of proof which would help them to surpass the limitations of the empirical induction which they used as a method to produce the idea for the solution, or as a student said in one of the groups at the Stockholm University: *"You need a formula of some kind, or at least something which sets* *aside all doubts. You cannot rely on something mysteriously visual. You need a general solution to all puzzles. That is, after all, the task".*

In five of the six groups the students managed to produce geometrical arguments, but although they seemed convinced by their own argumentation (*"Now we know that it holds. Now we believe in it"*) they doubted its mathematical relevance (*"This is not a proof, this is just a way of showing how it will turn out"*). In all of these groups the students posed questions about how to negotiate the foundations of their beliefs, how to assure themselves of the logic, how to turn their ways of reasoning into a solid argumentation. They could not, however, find any means by which to signify an arbitrary chessboard, and, in addition, an arbitrary placement of the defect (*"I don't understand how we are to describe where on the board the defect should be placed"*). They wondered how they were to depict a specific board with specific dimensions, and with the defect positioned in a specific place, and from such a point of departure prove that an arbitrary board could be covered (*"You choose one example, and at the same time you are supposed to prove that it works for all cases"*). The students seemed to lack the linguistic means necessary to provide the proof of their assertions.

And maybe other means as well. Empirical induction is, as the students all knew, not a valid method of proof. Even if they were to test a long chain of successive *n*:s they still would not have proven the assertion that all defective chessboards can be covered by L-pieces (*"We're not supposed to sit here just testing, are we? It works for this one, and for this one, and…"* or *"This is not a proof. This is just a way of showing how it will turn out."*). Mathematical induction, however, is a valid method of proof. Contrary to the inductive reasoning of empirical induction it is based on a deductive logic: a step-wise hypothetical reasoning founded on an axiom – the axiom of induction – which states the following:

> Suppose you have a set of natural numbers M with the following two properties:
> (1) $1 \in M$ (1 belongs to the set M)
> (2) $\forall n\ (n \in M \Rightarrow n+1 \in M)$ (For all natural numbers n, it holds that if n belongs to the set M, then its successor $n+1$ also belongs to M).
> Then M must be the set of all natural numbers **N**

In the language of logic:

$$[1 \in \mathrm{M} \wedge \forall n(n \in \mathrm{M} \Rightarrow n+1 \in \mathrm{M})] \Rightarrow \mathrm{M} = \mathbf{N}$$

In our case M is the subset of **N** consisting of natural numbers n such that the following statement P(n) is true:

> P(n): It is possible to cover any defective $2^n \times 2^n$ chessboard with L-pieces regardless of the position of the defect.

The students, however, did not seem to address the task of proving the proposition above within a context where the axiom of induction was accepted as true, and neither did they seem to be aware of the logic involved. The students knew that they could cover the smallest chessboard (*"Where n equals one"* as Irene stated), hence they knew that 1 must belong to the set M (1). The second part of the conjunction (2), however, consists of an implication, and this seemed to have been a major stumbling block to the students in all of the six groups.

What does it take to prove an implication A $\Rightarrow$ B? The statement tells you that **if** A is true **then** B is also true, which means that we only have to rule out the possibility that A is true and B is false. In all other cases the implication is true.

In order to prove the second part of the conjunction (2) above, we choose an arbitrary n (or k as the students in the group above preferred to call it). But how are we to choose such an n? This is what the students in all of the groups ask themselves in a variety of phrasings, and in posing such questions they tell us that they are not trying to prove the **implication**, but single statements about n. In using mathematical induction, however, we do not have to pose such questions, and this is the merit of the proof method. We just have to prove that **if** P(n) holds **then** P(n+1) holds. **If** it is possible to cover an arbitrary defective $2^n \times 2^n$ chessboard, **then** it must also be possible to cover the chessboard next in size, $2^{n+1} \times 2^{n+1}$, since it consists of four defective $2^n \times 2^n$ chessboards (one initially defective and the other three of the four constructed such that the virtual defects can be covered by an L, as Jacob said). This is all we need.

If we scrutinise the students' formulations when they summarise their solutions we can see that they have access to all the elements of the proof: they know that the $2^{n+1} \times 2^{n+1}$ board consists of four boards $2^n \times 2^n$, all 'defective' (*"Let's say that one out of four squares is covered. On the other three squares we place the holes so that they are available to all three. It's as simple as that. One is covered by the defect and on the other three we can choose where to place the holes"*). The consequent is however not linked to the antecedent – the if-then assertion on which the proof rests is missing, and without this prerequisite, without an understanding of the logical foundations of mathematical induction, the students are at a loss when trying to grasp the point of the method of proof (Wistedt, *et al*, 1997).

The problems that face the students thus seem to exist at a meta-theoretical level. Since this level determines the relevance of the information provided in the assignment, the students could not find their ways out of the dilemma facing them. The students lacked, as the teachers in the previous chapter pointed out, the prerequisite knowledge – the basic assumptions which would render the information meaningful, in this case the axiom of induction. Deprived of the knowledge necessary to solve the problem the only option available to them was to contextualise the task within the realm of empirical induction: the students investigated a number of defective chessboards, they found a general method to solve the problem for any given chessboard, but they did not find a **method of proof** that would take care of every possible counter-example, and hence they were not satisfied with their solutions.

The group above solved this dilemma in a playful manner. They exploited the rules of the mathematical discourse to circumvent the issue. As mentioned, mathematics works much like judicial law. What is not strictly forbidden is allowed. The text doesn't explicitly state that **mathematical** induction should be used, as Andy and Louise both noted. Hence, the students took the liberty to use any form of induction, or *"induction, almost"*.

The Merits and Limitations of the Collaborative Work Forms

The group work did not help the students to overcome their views of induction as algebraic in nature, and neither did it help them to establish the framework of the axiom of induction. Since all of the students shared the same limited notion of mathematics generally and inductive proofs specifically, no incitement for a change in views was introduced in the groups.

The divisibility problem was, however, discarded in five of the six groups. In all of these groups a member objected that *"we must consider the L-shape of the piece"* or "*This may be irrelevant, but what we have shown is that you can cover a chessboard with **threes**. They don't look like that"* (see Wistedt, *et al*, 1997), remarks which opened for critical reflection upon the interpretation of the task. In such cases the collaboration between the students served as a challenge to limited, taken-for-granted notions harboured by the individual students.

Co-operation between peers clearly has its merits. But limitations exist as well: If the students do not link mathematics to logic, if they do not understand what a proof is, or what characterises hypothetical reasoning, we cannot leave it to the students to find these things out for themselves, especially if we suspect that they share their cognitive shortcomings with the other students. The students need to interact with more experienced members of the academic cultures in order to overcome the limitations in their personal views of the subjects.

This means that we have to broaden the notion of collaboration to include not only the students but the teachers within the programmes as well. A crucial aspect of the developmental projects within the Government's initiative is the increased number of opportunities that the students have to interact with their teachers: in tutorial sessions, in assessment procedures, and in oral and written presentations of projects or assignments. In the next chapter we will investigate one example of such teacher-student interaction. The example is based on data gathered during a three-day assessment period carried out at the end of the third term of the programme for Scientific Problem Solving at Göteborg University. In this last chapter of the in-depth study we will examine how a co-operative and interdisciplinary assessment procedure can help the students, and the teachers, to reflect upon learning as a human practice rooted within traditions of knowledge which provide the disciplinary frameworks through which the world is viewed.

Interdisciplinary Assessment of Student Knowledge

The programmes within the Government's initiative offer the students a variety of work forms with the aim of aiding them in developing scientific attitudes towards the subjects studied. The problem is, however, how we are to know whether the individual students make use of the offerings. In the previous chapters we have described situations where groups of students co-operated in carrying out assignments, situations which provided them with the opportunities to relativise their own ways of thinking, to express their thoughts so as to make them understandable to others, and to listen to and make use of other people's arguments. We found, however, that there are certain limitations to what the students can accomplish in co-operation with their peers. Learning is, in part, a socialisation into existing disciplinary cultures, and the students cannot be expected to be fully acquainted with these cultures, and, hence, they need guidance from more experienced members of the disciplinary communities in order to develop knowledge which is not only personally but also culturally relevant.

How is it possible for the teachers to shoulder the responsibility of guiding individual students in their learning of mathematics, physics, statistics and the like, through forms of work which are collaborative and interdisciplinary in nature? Below we will open a dialogue on these issues.

The Case

Three commentators – one mathematician, one physicist and one representative of the labour market – were invited to read two group reports from an interdisciplinary project carried out by students in the third term of the programme for Scientific Problem Solving, and to comment on them in individual interviews.

The reports had as their main focus physics, more specifically electronics. They represented the study results from a course called "*From Signal to Information*" within which the students had devoted about five weeks to a group project in physics, mathematics and mathematical statistics.

The students started their projects by choosing something to measure, for instance the propagation of sound waves or the amount of UV-radiation under various weather conditions. In groups of six the students devised and constructed a measuring instrument. They used it to make observations, and in written reports and oral presentations they reported the results of their measurements to an audience of examiners, teachers and peers. The data used in this study comprises the students' written reports, four in all, and the groups' oral presentations, which were recorded on both audiotape and videotape and later transcribed in full. The students were also examined individually by three examiners – a mathematician, a physicist and a statistician. In groups of two the students were asked questions about their work. During these individual, oral examinations all of the pairs within the same study group received similar questions, for the sake of comparability and fairness.

The assessment procedure has been described in greater detail elsewhere (see Wistedt, 1997; Wistedt, in press). Below, some short excerpts from the different phases of the assessment procedure are presented to enable the reader to take part in the dialogue. Excerpts from the oral presentations and the individual oral examinations were also read by one of the commentators – the mathematician. The three examiners were also interviewed, two of them individually, and the three of them together in connection with a group discussion held in preparation for the oral examinations. On these occasions the interviewees gave their views on the merits and limitations of these forms of work, and on the qualities of the students' learning. All of the interviews were tape-recorded and later transcribed.

The Performances of the Student Groups

The most striking observation from the interviews with the examiners was that their opinions about the students' performances on a collective level diverged substantially; in fact the report which the physicist regarded as the best of the four group reports was judged as the worst by the mathematician and conversely.

Since the students were not supposed to receive separate grades in the three subjects involved, but a joint verdict of either 'fail', 'pass' or 'pass with honours', the examiners had to reach agreement on how to evaluate the students. The three aspects of the assessment procedure – the written reports, the oral presentations, and the individual oral examinations – were not graded separately either, but the individual students were to receive credits for their contributions to the work as a whole, and as a consequence the teachers had to discuss their respective evaluations of the group works as well as the individual performances within them. Some short excerpts from the discussion among the examiners will highlight their differences in opinion about the quality of the group projects:

A Discussion About the Students' Reports

– *Let's discuss the report written by group B, which is interesting since you think it's good and I don't,* said the mathematician and turned to the physicist. *Maybe you can say a few words about it.*

– *Well, first of all I find it easy to read,* said the physicist and continued: *They have described what they have done experimentally, and the report is fairly extensive in regards to background theory and comprehensive in its descriptions of what the students have done and how different parts of their instrument function, and on occasions they have tried to analyse their results – why they turned out as they did. Of course, they have made mistakes: Their way of testing the loudspeakers, for instance, doesn't work, but at least they have tried to figure out a way to test them. They have bothered to tell us how you could design a test. They have not just neglected the problem.*

– *Yes, and in my opinion the report is difficult to read,* said the mathematician. *There is a lot of chat and still you do not get a clear picture of what they actually have done. There are too many words used to explain very little. The language is informal in the wrong way. And…let's see…maybe I can detect things which you can't see, since you know what is supposed to be there.*

– *Exactly*, agreed the physicist.

– *Trigger, for instance*, continued the mathematician. *It says here that 'the oscilloscope started to trigger'. I don't know what the word means.*

– *No, that's jargon. Such things pass my eyes*, said the physicist.

– *Yes, but since the report is so verbose elsewhere you get the feeling that they explain some things in detail but let other things pass through without comments,* the mathematician concluded.

So, what is the verdict? Is the report 'comprehensive and extensive' or is it 'verbose and chatty'? And what can explain the differences in opinion expressed by the examiners above? In the dialogue below these questions will be discussed.

Differences in Disciplinary Perspectives

The statistician, who also took part in the discussion from which the excerpt above was chosen, commented on the differences in opinion between the physicist and the mathematician:

– *I can understand both of you,* he said. *The problem is the same in mathematical statistics. What group B tries to do, more successfully than the other groups, is to clarify what they have actually done. And even if this, in some sense, makes the report wordy, they are at least trying to explain what they have found out. But I know that there are differences between pure and impure mathematics, as I call it.*

The mathematician objected that it was not actually the mathematical parts of the report that were chatty. These were more to the point.

– *But that is not what I mean*, replied the statistician. *I mean the differences between your evaluation of the report and mine. I am much more used to this chattering about, to the 'story-telling', than you are, being, as you are, a pure mathematician. Regarding the statistical parts of the report I see definite advantages in their use of many words. The wordiness shows that the group has had the intention of telling others what they have done and what their results are.*

The discussion casts light on some important aspects to interdisciplinary work. Learning a subject is in part a process of adapting to a scientific genre. In this case, however, the students were addressing multiple audiences: mathematicians, physicists and statisticians were all supposed to understand the text. The problem is, however, that in adapting to one genre, in this case physics, the students may easily come to violate the rules of other genres, for instance the mathematical genres, where 'chattiness' is not held in high esteem. Technical language may also exclude readers, in this case the mathematician. Explaining technicalities, for instance what 'trigger' means may, on the other hand, be viewed as a bit naive within the physical sciences. Such matters make interdisciplinary work difficult.

On the other hand, you may argue that the ability to adjust to multiple audiences is a necessary part of the knowledge about a subject, and, furthermore, an aspect stressed in all of the programmes within the initiative. This aspect of the developmental projects was also praised by the representative from the labour market who pointed out that when experts from different disciplines meet they easily take their own frames of reference for granted:

– *And some experts have great problems bearing in mind that they address other human beings who actually wish to understand what their message is.*

The statistician seemed conscious of the differences in disciplinary perspectives. This may be due to the fact that many statisticians are accustomed to co-operating with colleagues from other disciplines, which may affect what ”they take as normal, natural, real, reasonable, expected and sane” (Hawkesworth, 1996, p. 91). Discussions, such as the one cited above, may, however, provide the teachers from other subjects, who are not as accustomed to interdisciplinary co-operation, with the same opportunities. In this respect the teachers who participate in the development projects are offered chances to broaden their understanding of the other subjects taught to their students. The concluding part of this report elaborates on this aspect of the projects in terms of in-service training.

Differences in Roles and Responsibilities

The reports were written by the groups and the groups were also given the opportunity to display and defend their work in oral presentations. One day was allocated to such presentations, during which the groups described and discussed the results of their projects with the other students and with the three examiners. Some of the teachers who had been tutoring the groups were also present. Each study group was entrusted with the task of scrutinising the contents of another group’s report, and to put forward critical questions during the debate.

The answer to the question above – was the report, discussed by the examiners ‘verbose’ or ‘comprehensive’ – was answered in a rather interesting way by the students who had studied the report written by group B. Their answer was that the report was **both** ‘verbose’ **and** ‘comprehensive’ depending on the perspective adopted. If the content was viewed in relation to the overall goal of the course – the goal of learning electronics – the report was found to be comprehensive in the sense that it provided *”many excellent and thorough explanations”*. On the other hand, if the text was viewed from the perspective of the reader it could be regarded as a bit chatty: *”There are many discussions about components that you do not use./…/ On the whole, it would have been better if you had asked yourselves what you actually need, and choose components that fill the requirements, instead of reasoning about components randomly, telling the audience why you did not choose this or that. It makes the text unnecessarily messy.”*

Roles and responsibilities vary and different responsibilities are not always easy to combine, for instance the role of being a well-informed student telling the teacher all that you have learnt about the subject matter, and the role of the efficient communicator, providing no more and no less information than is needed for a reader or a critic to follow a certain line of reasoning. The report written by group B concerned the measurement of sound waves. In the mathematical part of the report the students had introduced the wave equation. The other students asked them about the function of these calculations:

– Concerning the chapter about the wave equation:We were wondering what it was doing there in the first place.
– You'll have to ask our supervisor about that, said one of the students in group B giggling, but another student intervened:
– No, but he thought that it was more fun to calculate on the waves than on the currents in the circuits we had used. And we thought that since our work concerned sound waves, it could be a good idea.
– A nice application, added a third student.

Viewed from the perspectives of the communicator and the reader, the wave equation was redundant. Viewed from the perspective of the supervisor and the learner, the introduction of the wave equation was an excellent chance of applying some mathematics learnt in previous courses.

The clashes of roles was commented on by the mathematician who read the reports and the narratives describing the oral examinations. He noted that the roles of the subjects involved in the projects were very different. These particular projects had their main focus on physics, and:

> *– When examining the students, the physicist did not have to drag the students before a theoretical issue which he found interesting and worth reflecting on, and which reached beyond the local task. Such issues presented themselves readily. You couldn't help considering them. This was not, however, the situation for the mathematician. The mathematical issues that needed to be studied and were brought into light by the project were either trivial or beside the point. I may seem to be going a bit overboard and my wording may seem a bit harsh, but still I find that there is a problem lurking here.*

The problem can be described as a problem of how to combine the responsibilities of learning and the responsibilities of completing a project in an efficient way. Choosing the latter may have serious effects on the former:

> – *To put the matter in a nutshell,* continued the mathematician*: if, as a result, you solely take an interest in the mathematics needed for the moment, or that you believe are needed, you will not learn mathematics. You have to reflect upon the theories.*

The issue raised above is interesting and relevant to all of the projects within the initiative. In the next part of this report – the evaluation – we will return to the problem and we will discuss the various ways in which it is handled within the programme for Scientific Problem Solving and within the other programmes.

The Performances of the Individual Students

Limitations to the Collaborative Work Forms

The written reports and the oral presentations were all group performances. One limitation of such presentations is that they make it hard for the teachers to discriminate among individual levels of excellence. In the general discussion about inclusive education, a concern often expressed is that collaborative teaching methods, such as projects or problem-based learning, do not allow for stringent assessment of individual knowledge. Some students in the groups may, as a consequence, pass courses on the basis of fewer accomplishments than their peers. The examiners who took part in this study were well aware of this:

Examiner in mathematics: *I know that all of the students within the groups can't come up with the solutions presented in the group reports. Only some of students have such capabilities; I'm fully aware of that. A couple of students raise the quality of the work. Some of the other students follow them and some don't.*

The commentators also expressed their concerns about the quality of the individual knowledge acquisition within the collaborative works forms:

Representative from the labour market: *I can see definite advantages to the work carried out by the students: First of all the projects involve practical applications which I believe are beneficial to learning. Secondly the projects* *include investigations of the theoretical foundations of the work. Whether or not the level is reasonable is beyond my judgement, but they are there anyway. Furthermore, the projects include mathematics, statistics and reasoning about the sources of error – they are both practical and theoretical, which I believe is very good.*

The important thing, however, is that all of the students within the groups take an active part in the projects so that they can understand and make use of the critical suggestions offered by their teachers and peers. I'm not sure that they all can do that. The reports are the results of group works, but what are the contributions of the individual students? Spontaneously I feel that when higher education keeps expanding, and the universities live in their own world admitting as many students as they possibly can, the standards of quality may be lowered as a result. It's human to adjust to the circumstances, and if the students do not have the knowledge needed I don't think that they will gain enough from a project. One problem is that the students pass through the programmes at a different pace. The group work, however, will follow its schedule just the same. If some students lag behind in the theoretical parts of their studies, maybe they lag behind in the groups as well.

Such difference between the students may even get greater over time. During the examination process one of the examiners made a comment:

Examiner in statistics: *A thought which has struck me during these conversations with the students is that within this programme the students may diverge in terms of qualities of learning. I remember how these students acted a year* ago (referring to two male students who had just been examined). *They were in the same group then as one of the women, and the boys used to talk quite loosely at that time and she really knew how to reason quantitatively, but in a way they seem to have separated even further. Now the boys just talk and talk. Nothing but chat. No distinct answers to any of the questions. It seems as if they do not have the intention to probe deeply into the matters. Maybe such tendencies are strengthened within this programme, I don't know, but the thought suddenly struck me.*

In the chapter presenting the students' perspectives on the forms of work, a male student from Stockholm University expressed his concerns about the quality of learning developed within the collaborative work forms: *"I'm dead scared"*, he said, *"that the projects will be regarded as having low status."*

The concerns expressed above are relevant to the programme policies and they have to be dealt with, otherwise these attitudes may develop into a more general scepticism towards programmes designed to fill the needs of new groups of students. Such attitudes do not benefit the students recruited to the programmes, and hence, an inclusive education must take these concerns into account. Within the programme for Scientific Problem Solving, the problem is handled by supplementing the group assessments with individual, oral examinations on the students' understandings of the specifics of their project work.

The Individual Students' Understanding of the Subject Matter

One merit of oral examinations is that they allow for an investigation of broad aspects of student knowledge. The students' interpretations of the questions posed, their ways of organising an answer, and ways in which they phrase their answers can say a lot about their understanding not only of the subject matter in a limited sense, but of the subject as a whole and of the educational setting in which it is embedded.

The individual students within the respective study groups varied a great deal in their understanding of the work done, an observation which strengthens the importance of the concerns expressed above. Examples from the individual oral examinations of the students within the same study groups will illustrate the character of these differences.

Two Short Excerpts from the Physics Examination

The students in group A had constructed a measuring instrument and used it to measure the amount of UV-radiation on a sunny and a cloudy day. The physics examiner asked the students individually about the sources of error that the group had taken into account when discussing the results of their project. Two students, both female, answered the question in quite different ways:

Student 1: *Sources of error…you mean in the circuit?*
Examiner: *Mmm.*
Student 1: *Well, we have the sources of error that we can measure. First of all we have to consider the errors of the voltage-meter, and of all the components that we used which can deviate by this or that many percentage units. And then we have the sources of error…or we believe that the most important errors are our estimations. If you look at the diagram* (she directed the examiner to the page in the report and explained some problems concerning the approximations given)…*those are not very good estimations, but we could not find any alternative ways of estimating them. Then we have the fact that our instrument lets through some indirect radiation. We made some estimations of the filter, but the instrument lets some radiation*

through at this point (she pointed to a figure showing the instrument) *and there we have not made any estimations at all. Those are the most important sources of error as I see it.*
Examiner: *But you have presented some calculations of the errors, haven't you? The filter lets through 3% of IR-radiation, doesn't it?*
Student 1: *Yes those values are given. We thought that we had to have at least some grounds for disregarding the error.*
Examiner: *Some arguments then?*
Student 1: *Yes, at least to some extent.*

Student 2 answered the question as follows:
Examiner: *Can you tell me a little about the sources of error.*
Student 2: *The ones that we have?*
Examiner: *Mmm.*
Student 2: *Except the ones mentioned in our report?*
Examiner: *No. Those. If you have any else…*
Student 2: *Ah…well…what should I say? What we have not mentioned in our report is that we would like to improve our instrument by constructing a lens which gathers the radiation coming from different directions, in order to be able to measure all the light which comes in. Much that falls in is diffuse radiation and we really do not know what the margin of error is. And then* (she turned the pages in the report)…*you mean apart from the ones mentioned in the report, don't you? Or do you mean that I should give the ones mentioned?*
Examiner: *Yes. Please give an explanation to how you have reasoned.*
Student 2: *Well. What should I bring up? I can take this part, where we have calculated the errors which we know exist on the resistors and the voltage-meter, where we actually have calculated the error, the maximum error, or the margin of error…*

An intentional analysis of the answers given by the two students reveals some interesting and important differences between the two:

Student one interpreted the question from the examiner as an invitation to discuss the most important sources of error and she organised her answer accordingly. She started out by mentioning the errors that the group had been able to calculate, moved on to the errors that could only be estimated and ended up with errors to which no estimations whatever had been offered.

Student two, on the other hand, had difficulties interpreting the question. Her first thought seemed to be that the examiner wanted her to reproduce the sources of error mentioned in the report (*The ones that we have?)* a quite pointless intention since both the examiner and the student had access to the report. An alternative interpretation was offered: The examiner must have meant the sources of error which the group had not mentioned *(Except the ones mentioned in our report*?), an interpretation which was followed up in her third statement, where she told about an error which had not been taken into account by the group. The alternative interpretation was tested once more at the end of this statement in which she returned to her initial interpretation *(Or do you mean that I should give the ones mentioned?)* which was confirmed by the examiner. But how do you 'tell about' the errors mentioned in the report? What is the point of it?

Student two obviously had a limited understanding of what it means to 'tell about' results gained in a scientific context. Student one structured her answer in accordance with an overriding principle, in this case the importance of the errors in terms of how accurately they could be calculated and, hence, how correctly they could be regarded. Student two could not find such a principle which forced her into picking out errors randomly (*What should I bring up? I can take this part…),* she was forced, that is, into a reproductive mode of approaching the task.

The differences between the students raise some important questions which will be discussed in greater detail in the concluding part of this report: Have the principles of reasoning within a scientific context been addressed in the groups? Have the teachers and supervisors brought them into focus or have they just taken it for granted that the students will eventually understand the essentials of scientific reasoning? If so, what does this mean for those among the students who are not, by sex, social background or previous training, attuned to a scientific mode of thinking?

The oral examinations are, however, one of the occasions where students and teachers interact, and, hence, they offer the possibilities for the teachers not only to investigate whether the students have understood what it means to reason scientifically within the respective subjects, but also to communicate the essentials of such reasoning. One example from the interaction between the examiner in statistics and three of the students in group B will illustrate the educational merits of such interaction between a teacher and a student. In this case the communication took place during an assessment. It could have taken place during a tutorial session as well.

Two Short Excerpts From the Statistics Examination

The examiner asked the students about the statistical models used in the group report. The students had constructed a measuring instrument which measured the propagation of sound waves produced by guitar strings:

Examiner: *In the statistical part of your report you refer to some distributions. What distributions are these?*
Student 3: *Well, we assume that is has a normal distribution, the experiment on the strings that we made. But we have not been able to verify this. We had too few measuring points…or observations in order to use a normal distribution.*
Examiner: *That sounds reasonable. I don't object to that. You say that **it** has a normal distribution. **What** has a normal distribution?*
Student 3: *Well, in our case…well…the variation of the strings. The variation within the strings and between the strings.*
Examiner: *Well, many things can vary on a string. What has a normal distribution?*
Student 3: *Well, we measured the frequencies of the strings when we plucked them.*
Examiner: *Yes. So it is the frequency then?*
Student 3: *Yes.*
Examiner: *Yes. But there is another distribution involved too. Not just the normal distribution but another one.*
Student 3: *Well…we used a t-distribution I think…I believe we did that.*
Examiner: *Well, it's a good thing that you have the knowledge of matters outside of your report. But that is not the distribution you used.*
Student 3*: No. I thought that we did, but…* (silence followed)
Examiner: *Well, it's an F-distribution. It's good that you know of things outside of your own report, but what is an F-distribution? What magnitude is F-distributed? Is it the length of the strings or…what?*
Student 3: *No, I think it is …well…when we plucked them…we had an F-distribution of how much the frequencies deviated from our mean…of the strings…eh…of the strings, that is, the frequency…the mean frequency of the strings.*
Examiner: *So you used the double assumptions: the assumption about a normal distribution and the assumption about an F-distribution, or..?*
Student 3: *No, we used the assumption about an F-distribution…* (silence followed)
Examiner: *Okay.*

Other students in the group answered the same question as follows:
Examiner: *In the statistical part of your report…I want to talk a bit about the prerequisites for your calculations…What assumptions do you make, or what assumptions are your calculations based on?*
Student 4: *Well we assume that it has a normal distribution. We do not prove that actually. We just make a check.*
Examiner: *I see. **It** has a normal distribution?*
Student 4: *Well the population has a normal distribution. That which we make our tests on has a normal distribution.*
Examiner: *Well, population of what? The word refers to something. Population is also a general word which refers to something. What has a normal distribution?*
Student 4: *The frequencies.*
Examiner: *Yes. The observations that is, plainly speaking.*
Student 4: *Yes.* (The examiner elaborated on this question a bit further and then turned to the other student in the pair)
Examiner: *You have used an F-distribution as well, and I would like to pose a short question about that. How does the F-distribution fit into your work? Is it also an assumption, like the normal distribution for the observations, or..?*
Student 5: *It's the ratio between…*

Examiner: *Yes…mmm…*
Student 5: *…σ^2 and σ^2.*
Examiner: *Mmm. And that is, of course, under certain preconditions. You say that this ratio is F-distributed.*
Student 5: *Is it approximately F-distributed or…?*
Examiner: *It isn't an assumption then? Is it a proposition or what?*
Student 5: *Well, I can imagine that it is approximately F-distributed.*
Examiner: *Yes. And if it is approximately F-distributed…in mathematics we usually formulate our statements in terms of **if-then**.*
Student 5: *Yes, that's true.*
Examiner: *And when you say that it **is** in this way, we have a **then**. So we need an **if** as well.*
Student 5: (makes a little laugh)
Examiner: *And what could that **if** be?*
Student 5: *Except the assumption we have already made, then?*
Examiner: *Well, do you need any except those?*
Student 5: (makes a 2 second pause)
Examiner: *You mean that you need the assumptions already made then? That is, the normal distribution for the observations?*
Student 5: *Yes.*
Examiner: *Yes.*
Student 5: *But the question is whether they do not need to have the same standard deviation as well, maybe.*
Examiner: *Yes. That's a thought. But then again, if we have the same type of measurements…but it is a good thought.*
Student 5: *But our observations do not seem to have that.*
Examiner: *No.*
Student 5: *But that is, of course, another matter.*
Examiner: *Precisely. A good comment. A very good remark.*

Comments to the Individual, Oral Examinations

During the oral examinations the students use a lot of vague expressions. All of the students in group B, not only the three cited above, and not only the students in group B, answered the questions about the distributions used in much the same way*: We assume that **it** (or this) has a normal distribution.* In each of these cases the examiner asked the students what 'it' referred to. In asking for such clarifications it became quite clear which students knew the meaning of the calculations made in the report and which did not. What also became clear was that the questions had not been brought up in the group discussions since all of the students needed a lot of help from the examiner to reflect upon the matters.

In everyday talk we often use vague language since it serves the purpose of minimising differences in opinion. A conversation may run smoothly even if the communicating parties are not in complete agreement on the definition of the words used. The use of language in informal settings differs a lot from the use of language in formal or institutionalised settings (e.g. Bernstein, 1973). Language usage is inextricably entangled with social activities (see e.g. Rommetveit, 1990; Levinson, 1992; Coates, 1993) which means that the students' ways of phrasing their answers can tell a lot about their understanding of how natural scientists approach the matters discussed. The student may, for instance, have a limited understanding of the importance of specifying referents or populations in a statistics discourse.

An alternative interpretation of their vagueness would be that they are trying to guard themselves from making mistakes. The more specific their answers are the more likely it is that they reveal their misunderstandings. An oral examination is also a social activity, and an activity of a very special and asymmetrical kind, where one of the communicating parties has the responsibility of judging whether the students' ways of knowing the subject are in accordance with culturally accepted norms. Vagueness in language can be interpreted as a strategy to counteract such an asymmetry in roles. Maybe the examiner will prove to be lenient and presuppose a shared understanding. However, since all of the students found it more or less hard to produce an answer even when the questions were elaborated by the examiner, the first interpretation seems the more likely.

In the study groups the students are among friends, all of whom work on the same project. In such a setting things can easily be taken for granted: referents can be excluded since others will probably know what terms refer to, or at least such an attitude could easily develop within a group. Asking people to make their utterances precise can even be viewed as disruptive in such a setting. Why bother about details?

Yes, why bother? What is the meaning of the meticulous search for referents displayed by the statistician, and what purposes does it fill in the conversation with the students?

Merits and Limitations of Teacher-Student Interaction

First of all, careful questioning helps the examiners to inform themselves about the quality of the student's understanding of the concepts used in the report. Student three, for instance, did not seem to know that a normal distribution and an F-distribution have different roles within the statistical model used: the assumption about a normal distribution is a model assumption which can never be proved or disproved; it can only be viewed as more or less reasonable. The statement that the ratio between the two variances is F-distributed, on the other hand, is not a new assumption but follows logically from the assumption about the normal distribution. In the two last sentences of the communication between the examiner and student 3 above, it becomes very clear that the student does not know that.

Secondly, but no less importantly, it helps the teacher to communicate to the students the nature of statistical reasoning. Rigour and clarity are, of course, essential aspects of scientific reasoning in general, but maybe clarity in the use of referents is particularly important within a subject such as statistics. The statistician pointed to the differences between 'pure' and 'impure' mathematics in the dialogue about the differences between the examiner's evaluations of the group reports. A pure mathematician deals solely with the abstract world, statistics, on the other hand, is an applied science; to understand the differences between models and empirical facts is important to a statistician, maybe even more important than it is to a physicist, for example, since the empirical reality to which the models are applied may differ substantially from one situation to the other. In statistics you can never take for granted what words and expression refer to since the referents may vary from one investigation to the next.

If these are the reasons for the careful questioning above, these reasons are not communicated to the students in a direct way, with one exception: In the conversation between the statistics examiner and student 5, the examiner points out that in mathematics *"we usually formulate our sentences in terms of **if-then**"*, an utterance which directs the student's attention towards the use of hypothetical reasoning within the subject. More often, however, the essentials of the reasoning within the subjects are communicated in a more indirect way, for instance, the importance of keeping apart model assumptions and statements about empirical findings (as in the utterance: *"It isn't an assumption then? It is a proposition or what?*). The message may, however, reach the students even if communicated indirectly, at least those students who are aware of the fact that the discursive rules may vary between subjects and between different social settings, that is, students who are acquainted with the fact that the ways of attending to the world are heavily dependant on what questions are asked, what kind of knowledge is sought, and what forms of evidence are accepted.

Concluding Remarks

The results from the study reveal that it is not only possible for the teachers to guide the students in their learning of the various subjects involved in interdisciplinary co-operation, but that such forms of work offer a range of possibilities for students and teachers to reflect upon their own frames of reference, which are often taken for granted in a single-subject setting. We found, however, that the students do not always take up these offerings. This is not necessarily because they are reluctant or unwilling to do so, but because not all of them can find ways of making use of the messages communicated on a meta-level of conversation, that is, the level of discourse where the conversational rules are established, rules that work by convention and that constitute a common world of shared norms which make the social activities within a particular setting meaningful to the communicating parties. Since not all of the students are aware of these conventions, or even aware of the fact that there **are** conventions to be observed, they may have problems interpreting the activities of their teachers. This means that even if it is possible to create favourable learning conditions, the students' previous experiences may mean that these conditions are not fully utilised. This is a limitation worth heeding in the evaluation of the outcomes of the Government's initiative.

In the four chapters within this part of the study we have described in depth how students carry out tasks in co-operation with their peers. The descriptions were offered as a basis for dialogues focusing on the merits and limitations of the collaborative forms of work as means for enhancing the quality of student learning. The students' appreciation of what is worth knowing, what counts as knowing and what characterises knowing in an academic setting is inextricably linked to the norms manifest within the social setting in which learning takes place, and, hence, critical reflection upon this setting is a necessary prerequisite for successful learning and teaching. A critical stance towards the social norms that form the foundation of the existing pedagogical praxis is also intimately linked to the notion of developmental work as a way to improve the quality of university teaching. Interdisciplinary work seems to call for such critical reflection.

Many questions have been raised in the dialogues and many suggestions for change have been brought up. In the next part of this report we will summarise the results of this study and bring them together in a discussion of the outcomes and of their meaning in a gender-inclusive context.

4: Evaluation

An Inclusive View of the Outcomes

The aim of this evaluation has been to open a dialogue on a Swedish government initiative directed towards the development of inclusive degree programmes at the tertiary level of education – programmes designed to increase female participation in areas of inquiry dominated by men and to enhance the quality of teaching within higher education by implementing new teaching methods believed to appeal to these new groups of students.

The evaluation has focused on the two goals expressed by the initiators: the recruitment goal and the pedagogical goal of improving university teaching to meet the demands of students who are not for reasons of sex, class or previous training familiar with a scientific or technological mode of thinking and reasoning. Two questions were formulated in the introduction to this study:

- Have the projects been successful in their recruitment of new groups of students to the programmes, female students in particular?
- What characterises the teaching methods implemented within the programmes and in what respect can they be said to fill the students' needs in terms of developing their understanding of the subjects taught?

In this concluding part of the report we will try to answer these questions on the basis of the results presented in the previous chapters, and to discuss their meaning in an inclusive context.

The Recruitment of New Groups of Students

As pointed out earlier in this study, one limitation to this evaluation is that it only covers the first two years of the development projects and hence we can only provide a picture of trends. In order to gain a more conclusive view of the impact of the initiative we would need to conduct further studies which include the long-term effects of the recruitment efforts.

Below the recruitment trends are summarised in short sentences in order to make it easier for the reader to get a clear view of the outcomes. Please note that these sentences do not state facts that can be accepted at face value, but introduce topics which will be commented on and modified in the discussion about the results.

A Short Summary of the Recruitment Results

From part one of this evaluation we learnt that:

- The recruitment results vary among the programmes, from 56% to 15% female entrants
- These percentages increase in all of the programmes during the second year, considerably in some of them
- New programmes tend to attract more female students than degree programmes which are developments of more established programmes
- Female students tend to leave the programmes to a greater extent than male students do
- Students who do not have a natural science background tend to leave the programmes to a greater extent than other students do
- Female students are over-represented among students who do not have a natural science background
- Students who do not have a natural science background have lower grade point averages than other students have. They also perform less well on course examinations, but no definite conclusions can be drawn as to whether this is due solely to their lower grade point averages.

These are the main results, but what conclusions can be drawn from them and how can they be accounted for in a gender inclusive perspective?

Delights and Distresses

First of all we can conclude that the projects, on the whole, have succeeded in their ambitions to recruit students from non-traditional student groups. If we exclude the computer science programmes at Chalmers and Karlstad University which score slightly under average in their recruitment of female students in comparison to the mean percentages available in the national statistics, all of the other programs score well above average. In 1996 five of the seven programmes had reached the desired goal of recruiting at least 30% female students to studies in mathematics, science and technology, subject areas traditionally dominated by men.

From a gender perspective these are promising results. One draw-back is, of course, that the computer science programmes remain problematic in terms of female recruitment. As mentioned in the second part of this report we cannot provide any explanations of this other than the observation that these programmes do have a history. People may have formed views not only about computer engineering programmes as dominated by men but of men with hacker-tendencies and with extensive experience in handling computers. As we could see from the case study carried out at Chalmers, one of the students was able to give a fairly accurate description of an ideal-type Chalmers' student after just a few months on the programme, which tells us that ready-made opinions exist in society and may, even if inaccurate, influence the career choices made by the prospective applicants.

We also pointed out that the revisions of the programme policies within the computer science area may be rewarding in the long-term perspective. The teachers recognised the views of the ideal-type engineering student as founded on learning strategies functional in an educational environment characterised by a heavy reliance on the continuous testing of the students' successful reproduction of knowledge and skills. However, the programmes are not only the objects of the formation of such attitudes: they are actors on a social scene where these attitudes are formed and, hence, may change as a result of changes within the educational system. This means that the revised programmes may contribute to the formation of future attitudes towards computer science and engineering programmes, changes which in the long run may effect their recruitment profiles.

What Characterises Teaching Within the Programmes

What can explain the rise in the female interest in science-related studies observed within the other five programmes? What characterises the programmes within the initiative?

Making Room for New Groups of Students

First of all they are new programmes not yet occupied by any group which may call themselves an in-group. Thus they are less likely to be burdened by preconceived notions about what kind of student you must be in order to fit in. This may, in itself, function as an invitation to university applicants who have not before found their places within traditional science courses. Ideal-type notions may, however, develop in the future, and as some of the students expressed in the interviews described in part three of this study, such ideas seem to be developing, for instance the notion that you need to have the will to co-operate in order to gain fully from your studies: *"If you do not know how to work in a group, or lack the ability to learn, you shouldn't be here."* Either male or female, the students who attend these new programmes need to be self-directed in their studies *"or at least strive in that direction"*.

Co-operative Work Forms

We have not been able to find any data to substantiate the notion that female students in general prefer co-operative forms of work. Some of the female students who were interviewed actually denied that they had preferences for group work. We will return to this issue later, but whether this assumption is true or not, the implementation of the alternative work forms, i.e. alternative to the traditional lectures and exercises, signal to prospective students that **teaching matters** within the programmes. The teachers have at least asked themselves how teaching should be organised in order to promote student learning; they have expressed their concern by re-thinking their ways of teaching, which in itself may function as an invitation to those students who are sensitive to the learning environment. If you have already made up your mind about your career choice such things may not matter much. You will know that you want to study mathematics or physics or computer science no matter what. But if you have doubts about your choice of subject area, or harbour beliefs that you will not be able to make it unless you are cared for, such considerations may be of vital importance.

Problem-Solving Approaches to Learning

The problem-solving approach is another characteristic of the programmes within the initiative. Such approaches were more or less prerequisites for receiving funds from the Council. Below we will elaborate on this aspect of the programmes, but in this context it is sufficient to say that the students seem to link problem-solving approaches to certain conceptions of learning – as quests for a more thorough understanding of the course content. Judging from the interviews and from the essays which were part of the admission procedure within some of the programmes, the students carry hopes that learning within these new programmes will be something other than a mere reproduction of knowledge and skills, and when they express their dissatisfactions with the pedagogy, they point out that such qualities of learning are lacking even within these programmes: the risk of developing shallow knowledge, the lack of guidance which forces the students to find out the fundamentals all by themselves, and the fact that the projects may not always encourage problem-solving approaches (*I thought that they were supposed to engage us in experimenting, not just reading and summarising what others already had found out*). Even if they are not altogether successful, the introduction of problem-solving approaches signal to the students that the teachers are sensitive to a variation in qualities of student learning, in short that **learning matters** within the programmes.

Interdisciplinary Co-operation

The interdisciplinary work forms offer new combinations of subjects – mathematics, physics and statistics as in Stockholm, mathematics, physics and environmental sciences as in Göteborg, or mathematics, design theory and marketing as in one of the programmes in Karlstad. This means that the individual subjects are presented in new contexts, which not only broaden the view of what the individual subjects can offer, but also influence the very cultures of these subjects. We will elaborate on this matter below, but for now it can suffice to say that what the inter-disciplinary approaches tell the students is that the whole **academic setting matters** to the programme organisers, not only the subjects in a limited sense, but also their links to other fields of interest and to issues relevant to society.

The recruitment procedures are additional factors which contribute to this broadening of perspectives on natural science studies. As mentioned, three of the programmes used written essays as part of the admission procedure. Even if these essays did not, in any direct way, affect the possibilities for single students to enter the programmes, they may have been important as policy markers, telling the students that qualifications other than grades were appreciated within the programmes, merits not traditionally viewed as relevant to subject areas such as mathematics, physics or technology, for instance communicative skills. The possibility of using supplementary recruitment procedures, however, no longer exists. Standardised admission procedures are now prescribed by the authorities (Prop. 1995/96:184; National Agency for Higher Education, official letter, registration no. 80-1793-96). An application from the mathematics and physics departments at Stockholm University (dated May 5, 1997), with a request for permission to use written essays on admitting students to the Project Programme was denied by the National Agency for Higher Education. From an inclusive perspective this does not seem to be a very wise decision.

Broadening the Views of Education

There are other characteristics to be mentioned. The study-rooms, for instance, equipped with computers and other facilities are resources rarely offered to undergraduate students enrolled in traditional programmes or single subject courses. In some of the programmes within the initiative, the students are, in a literal sense, offered room within the academic cultures. The message sent to these students is that the **social environment matters**. Studying is not just a matter of attending lectures or passing exams, of gaining something from the programmes but also a matter of contributing something to the intellectual milieu. One of the mathematicians who took part in this study had a word for this interchange of ideas – the 'knowledge osmosis' – a conception which calls attention to the day-to day exchange of views which takes place in an academic environment, and which is essential not only to the fully initiated members, but also to those who are new-comers.

Promises and Actualities

Much is promised within the programmes, and all these promises may lead to high expectations among the students. If we view the drop-out rates from this perspective it is not hard to understand why some of the students left the programmes. These students also seem to belong to a group to which it matters a great deal whether their expectations are met or not – students who do not have a natural science background, which means that they do not belong to the traditional in-group of students in mathematics, science or technology. Many of them belong, in addition, to another minority group – they are female students. Some of them may, of course, have misread the promises. One of the interviewed students expressed the opinion that some of the drop-outs believed that the new ways of working would make studying less demanding in terms of time and effort, and that this explained why these students left the programmes. It does not seem likely, however, that all of the 58 students who dropped out during the first two years, of which 24 belonged to category D, and 26 were female students, held such beliefs. As suggested in part two of this study, we may be confronted with a vulnerable group of students and below we will elaborate a bit further on some aspects of their presumed vulnerability.

There may, however, also be other vulnerable students who were not identified statistically but pointed out by one of the teachers at Chalmers: students who are used to reproducing knowledge handed over by authorities, who have been successful with their strategies in upper-secondary school, but who fall short when confronted with demands of a very different kind in an academic setting. This is another form of vulnerability which seems difficult to handle in a context where the self-directed learner is the ideal-type student. Some of these students will, no doubt, be female students, since many young women take it upon themselves to fill the social demands put upon them by their teachers (cf. Wistedt, 1987). Finding ways of bridging the gap between the learning culture in upper-secondary school and the cultures of these new programmes seems therefore to be an important responsibility for the programme organisers.

The New Forms of Work as Strategies for Raising the Quality of Student Learning

When reflecting on the pedagogy implemented within the programmes, it is tempting to focus on the **forms** of the changes made. When innovations are introduced, they tend to attract attentions, and these forms of work are, no doubt, new not only to the students on the programmes but to their teachers as well. On trying out new ways of organising teaching and learning, you may find yourself occupied by figuring out answers to the question of how to implement these new ways of carrying out your work, rather than reflecting upon them as means to **alternative ends**.

Activities such as collaboration, problem solving or inter-disciplinary work are not meaningful in themselves. They must be evaluated in the contexts of certain goals. However, if you are moving away from traditional teaching methods, you may easily come to view certain activities as meaningful only in relation to traditional aims: training, meticulous calculation, substantial practice in solving standardised problems, for instance, may be linked to the goals of promoting rote learning and hence as activities to leave behind as you move on towards more student-centred teaching styles. In such a situation it is easy to over-emphasise the importance of *"understanding the ideas"* while *"making light of the mechanical side of learning"* as one of the teachers at Chalmers put it, only to find out later that both aspects of knowing are essential to an advanced understanding of the subject matter.

However, what is offered within the programmes are not certain forms of organising the work, but new ways of approaching, for instance, standard tasks. New goals are formulated which motivate the changes in work forms:

the goals of promoting enquiring attitudes towards the subjects studied and broadening the views of these subjects to include their relations to other fields of interest and to matters relevant to the society.

To implement new goals is far more difficult than to implement new teaching routines, and far more challenging. Many of the students, teachers and commentators who have contributed to this study were well aware of this. Below we will contribute to their on-going dialogue about the programme policies by approaching the new forms of working from a perspective which focuses on them as means to the end of aiding the students in developing creative, problem-solving approaches to learning, not least those students whose previous training, background knowledge, and attitudes towards studying may differ from the knowledge and attitudes formerly expected of entrants to science or technology programmes.

The Collaborative Forms of Work

The Diverse Functions of the Work Groups

Collaboration serves many purposes within the programmes. As one of the teachers at Chalmers pointed out, the study groups are resources which may be used for the aims of gaining insight into problems, exchanging ideas, gathering information, sharing work, and a range of other purposes. From the interviews with the student we also learnt that the study groups serve social purposes: newcomers to the programmes find friends among the group members with whom they can discuss matters other than the course content.

A conception which joins together all the diverse functions of the study groups, some of them listed above, is the conception of learning as a process of gaining knowledge by interacting with the content in dynamic ways which include exchanges with teachers and peers. Modes of teaching establish the environment, the situations, and the tasks. The students are supposed to approach these situations in a creative, problem solving way by trying out interpretations and posing questions, and some of the situations we have studied clearly have qualities of that kind. The students enquire into the specifics of the content, they discuss, debate, and negotiate the meaning of concepts brought to the fore by their assignments, as in for instance the examples provided in the chapter about the students understanding of mathematical induction. These examples give accounts of situations where the students make use of the work forms, not least the female students who, as one of the teachers at Chalmers said, *"take up a lot of space"* in the group discussions.

Conflicting Aims

The functions of the groups to facilitate student learning may, however, come into conflict with their social functions. As some of the female students who were interviewed said, group members may be led astray by the other members' needs to socialise: "*there is always someone who starts talking about other matters"*. If you are socially skilled and have the ambition to adapt to the needs of the other group members this conflict of interests can become problematic. One of the female students said that she had problems concentrating on the assignments since she could not find the time to think for herself while being among others, and another female student said that she found the distractions irritating since she wanted to concentrate on her studies*: "I'm 27 years old and I am in a bit of a hurry"*. Students who are socially sensitive may also take on a great deal of responsibility for the organising of the group work, as reported by some of the teachers at Chalmers, responsibilities which may be harmful to their studies. From a gender perspective these dimensions of the collaborative work forms are worth reflecting on, especially if we ascribe to the female students a tendency to be socially perceptive.

Defining Common Aims

Research shows that there is an upper limit to the size of a well-functioning work group (e.g. Granér, 1991, pp. 83). A group of more than eight to ten people may have problems organising their work. The groups described in this report vary from three to eight students, and the larger groups clearly had greater problems in activating all members and in finding a common direction for their work in a problem-solving context. Research also shows that large groups often spontaneously split up in smaller groups (*ibid.*), a process which could be observed in some of the groups at Chalmers.

Furthermore, if the responsibilities for carrying out the assignments are shared among many students, the demands on an individual student become less clear and distinct. Viewed from the perspective of a more inclusive education this is a crucial aspect of the collaborative forms of work. Students who do not have a background in the natural sciences may find it difficult, at least in the beginning of their studies, to contribute to the group discussions. If they have doubts about their own capabilities they may rely on others to carry out the work. In a large group there is a broad spectrum of social roles to play, and there will be ample opportunity for students who are less sure of themselves to take on relatively passive roles in relation to the topics discussed. In such cases these collaborative forms of work may obstruct rather than enable progress toward the goal of promoting student learning. Students who just *"talk and talk"* with no intention to *"probe deeply into the matters"*, as was noted by one of the examiners in the previous chapter, have obviously not found ways to further their understanding of the content by exchanging ideas with their peers and tutors.

Limitations to Group Work

The results of our study show that the approaches to learning adopted by the students may be limited by their conceptions of what counts as knowing in an educational setting, their learning strategies in the very broadest sense. Some approaches to learning carry attributes which make it hard for some students to take advantage of what is offered within a study group: These include the focus on the outcomes of learning rather than on the process of gaining insight, the individualistic, competitive mode of acquiring knowledge, and the reliance on authorities, in fact, they may undermine the very idea of learning as a joint constitution of insights.

This fact was clearly expressed by the groups at Chalmers who solved the examination task. Many of the students adopted a reproductive approach to the situation, that is, their intentions were to find the right answer to the question posed in the text rather than trying out suggested solutions to the problem. Thus, they put their trust in those of the group members who were believed to know how the task should be solved (*Because in our group we usually let those who really know something explain to those who don't*), sometimes reluctantly since these students had difficulties making themselves clear to the others. As the teachers who commented on the narratives noted, there was no real dialogue in the groups, the students were focused on the results rather than on the process of interpreting and solving the task, and hence, they did not take the time to toss and turn the questions or the examples offered by the group members.

The only way for these students to benefit from the co-operative forms of work would be to change their views of learning, and the only way for the teachers to communicate such changes in views would be to engage in a supervision process involving the articulation of the alternative learning goals. In one of the case studies we gave accounts of such an interactive process in which the cognitive practices of the subject cultures were directly or indirectly communicated to the students. In the examination study we described how the teachers searched for ways of learning about the students' misunderstandings, and how they intervened to change them by directing the students' attention towards relevant aspects of the subjects. Note that these interventions did not merely focus on the outcomes of learning but rather on the ways in which the students approached the subject matter.

In terms of a more inclusive education such interventions are of major importance. Cognitive practices, such as common sense, religion, social science, or natural science, all construe the empirical realm differently: they identify and emphasise different aspects of reality, and they ascribe meaning to phenomena and events in different ways. Students who have little experience of the habits of thought employed in a natural science context may need guidance in order to formulate their experiences in a culturally relevant way. To acknowledge this need is to take the inclusive policy seriously.

The Problem Solving Approaches to Learning

The problem-solving approaches: the open-ended tasks, the projects, and the 'vignettes', do not in themselves facilitate learning. Assignments, whatever form they take, have to be interpreted by the learners, and, as was pointed out earlier in this study, the intended interpretations, even if obvious to an informed reader, may be far from obvious to the students. One of the commentators at Chalmers noted that the task of finding the fault in a proof required an acquaintance with the mathematical culture: *"For a professional mathematician it is quite clear what the text* ***means****"* but for the students, with their limited understanding of what constitutes proofs in a mathematical context, it was very hard to *"know exactly where to look for the fault in this proof"*.

The same difficulties in interpreting the task were found in the case study where students in Göteborg and Stockholm discussed the problem of mathematical induction. They could not relate their method of proof to a geometrical context, not even when given opportunities to interact with other students, since they all shared the same notion of inductive proofs as algebraic in nature. In other words, they needed help in order to define the problem in a mathematically relevant way.

Defining Problems

In traditional teaching the task of helping the students to define problems is often met by presenting standard tasks defined in terms of procedures or algorithms used to carry them out. This means that the students are never confronted with the problem of delimiting ambiguous situations. It also means that the creative and heuristic aspects of the subjects remain hidden from the students. Within the programmes linked to the initiative, however, such aspects are brought into focus.

Putting an emphasis on the students' problem-solving capabilities facilitates questions which are rarely asked in traditional teaching: questions about the nature of the subject knowledge, meta-theoretical questions which, when asked, illuminate a range of theoretical presuppositions informing the cognitive practices of the academic cultures— What is a proof? What is a variable? What is the character of hypothetical reasoning? – and similar questions raised by the commentators within the in-depth studies.

Addressing Meta-Theoretical Issues

The results of this evaluation indicate that the teachers have paved the way for such meta-theoretical questions by encouraging the students to enquire into the fundamentals of the subjects, but they have not, as yet, fully investigated the consequences of these new approaches to learning. The teachers have re-defined their views of learning, and they seem aware of the fact that the students must engage in a long, sometimes frustrating and chaotic process of constructing and developing their understanding. In all their diverse expressions, the comments on the case-studies show that the commentators know that teaching involves making learning possible and that this implies an awareness of the differences in the students' ways of approaching the subject matter. Their comments can also be viewed as expressions of a gender perspective, that is, a perspective which acknowledges such differences in the students' experiences and backgrounds and appreciates them as crucial to the learning process.

Making Use of the Problem Solving Approach

The students may, however, find it difficult to adopt a heuristic approach to their tasks. We have already mentioned their views of learning as an impediment to interpreting and negotiating the meaning of the assignments. But there are other obstacles too. The students compare their knowledge to the knowledge of students who attend traditional programmes: How do they stand in comparison? Will they be as able to compete for the future jobs, and will they be as capable of meeting the demands put upon them at higher levels of education? Is it as rewarding, in terms of learning, to carry out a project as it is to attend regular courses? Such uncertainties seem to push the students into thinking about learning in quantitative terms: Had they attended regular courses they would have learnt **more**. Cramming and reproducing formulas makes it easier to evaluate what is learnt, at least in terms of pages or assignments covered, than does reflecting upon the subject matter in discussions with others.

Another obstacle which militates against the problem-solving approach to learning is the difficulty of coping with conflicting aims. During the course of their work the students come across questions of which they would like to further their understanding. However, in order to carry out their projects efficiently they may have to leave these questions unexplored. In the interviews a student pointed out that such dissonant aims may lead to a development of shallow knowledge, that is, a lack of *"understanding of the context of the concepts"*. In the previous chapter we described this problem as a problem of combining the responsibilities of learning and the responsibilities of completing a project in an efficient way, or, in other terms, to combine *content-related problems* and *procedural problems* (Halldén, 1982, 1988; Wistedt, 1987). The latter refers to interpretations of the task which are not related to theoretical or methodological issues, but rather concern the forms for coping with such issues, that is, practical problems of interest only in the context of the local task; the former refers to interpretations of the task actualised by the theories and descriptions brought to the fore, that is, problems of a general interest which reach *"beyond the local task"*, as one of the commentators put it.

Restricting the enquires to matters immediately relevant to a local situation may affect the possibility of reflecting upon the theories. Research has shown that if procedural problems dominate the students' enquires this may in fact, as the student above feared, lead to shallow knowledge (*ibid*., cf. Bergqvist, 1990; Bergqvist & Säljö, 1994), that is, to a surface-level processing of the task content (Marton & Säljö, 1976a, 1976b).

In some of the programmes this problem is dealt with by opting for the learning aspect. In Problem-Based Learning the students do not engage in projects. Their task is to learn and to utilise the means available to reach this end. In the programme for Scientific Problem Solving, as in some of the other programmes, the problem is handled by changing the roles of the subjects studied. The project described in the previous chapter had its main focus on physics and within this area the students were offered the possibility of addressing theoretical issues. In other projects other subjects may play similar roles, which means that theoretical issues relevant to mathematics, or statistics will not remain unexplored.

Another solution to the problem, often suggested in the discussions about the recruitment of female students to mathematics and natural sciences is to stress the goal of carrying out a project, with the argument that applied perspectives on the subjects will be more appealing to female students since women are more inclined to accept knowledge put into practical use. Such a solution may have its merits: The students will learn how to organise their work, how to resolve conflicts in a work group, how to gather information, how to communicate results in oral and written forms, and a range of other matters which may be viewed as relevant within programmes that stress such competence. If practical goals are allowed to dominate, however, this could mean depriving the students of the opportunity to engage in theoretical enquiry, which clearly would be doing them a disservice (cf. Hanna, 1994, Wistedt, *et al*, 1997).

Our results show that the problem-solving approaches require an awareness of the overall aims of introducing more open-ended tasks to the students. The teachers must find ways to balance the **know-how** or design-oriented approaches to problem solving, and the **know-why** or theoretical orientations (Kjersdam & Enemark, 1994). The results from this evaluation tell us that such a balance has not yet been reached in some of the programmes.

The Inter-Disciplinary Approaches to Learning

The work forms also aim at developing a broad understanding of the subjects by integrating different subject perspectives and by helping the students discriminate among complex patterns of interpretation.

When the students are assigned tasks which concern more than one subject area they are confronted with questions of how to approach these tasks. What aspects should they pay attentions to, and what questions should they pursue? As mentioned above, academic disciplines may be regarded as cognitive practices replete with theoretically constituted rules and conventions. Since these rules often operate on a tacit level they may be hard to unravel, not only for those who are seeking entrance into the cultures but also for

those who are fully socialised into them, and for whom the theoretical perspectives constitute a 'natural attitude':
"…an attitude of 'suspended doubt' with respect to a wide range of issues based on the conviction that one understands how the world works" (Hawkesworth, 1996, p. 91).

Differences in Subject Perspectives

The fundamental questions posed by the commentators on this study, such as the question *"What is a proof"*, may be answered quite differently within the context of mathematics and within the context of computer science. Perhaps this difference is not manifest in terms of what constitutes a 'correct proof', but obviously in terms of what constitutes an 'exemplary proof'. As was described in the chapter about the assessment procedure, the norms of how to communicate knowledge also differ among subjects. Again this difference does not turn up in terms of logic and sound reasoning, but rather in terms of preferences for different communicative styles and conventions (Wistedt, in press).

All these considerations belong to a meta-theoretical realm. Interdisciplinary co-operation promotes reflection upon this realm and raises issues which are rarely addressed in a single-subject context. In such a context it may even be viewed as a bit pretentious to address questions about the foundations of subject knowledge. These are often left to the great men to reflect upon, to the 'founding fathers' (see e.g. Hadamard, 1954; Hardy, 1969; Penrose, 1990). However, since the meta-level determines the relevance of information given in instruction (for instance the axiom of induction as a prerequisite for understanding inductive proofs, or the necessity of understanding what a proof is in order to appreciate the merits or faults of a certain proof), the students' notions of these meta-issues have to be challenged if they are to gain a thorough knowledge of the subject matter (cf. Renström, 1997, p. 11).

Aspects of In-Service Training

Highlighting meta-theoretical issues may also help the teachers to acquire broader views of their subjects. This means that the projects may have staff-improvement effects in the sense that they will provide the teachers with the opportunity to reflect upon their own perspectives since these perspectives are challenged in the discussions with colleagues from other disciplines. The case-study presented in the previous chapter showed how differences in opinions about the criteria used to assess student knowledge invoked discussions about the cultural specificity of knowing. The study at Chalmers, however, showed that such discussions do not necessarily follow from interdisciplinary collaboration. If the parties involved find it difficult to appreciate the merits of alternative ways of viewing a matter of common interest (e.g. the variation in views on mathematical proofs), that is, if they have difficulties approaching the variation in perspectives in an inclusive way, they may try to resolve the discussion by excluding perspectives, with arguments that, for instance, refer to the power structures prevalent in Academia.

Such exclusive strategies are, of course, alien to an inclusive policy. When the participants reach such dead-locks in their discussions they may need help from a third party to resolve the conflict (e.g. Gergen & Gergen, 1986, p. 303) and to reintroduce a heuristic orientation to the discussion. Such supervision can be arranged in various ways: In the examinations study, for instance, the statistician adopted a mediating role by pointing to the variation in perspectives which generated the differences in opinions. Pedagogues may also function as such mediators (cf. Renström, 1997). In short, the teachers, as well as the students, need supervision in order to make full use of the possibilities inherent in the alternative approaches offered within the programmes.

An Inclusive Perspective on the Inter-disciplinary Work

What makes a variation in perspectives crucial in an inclusive context? Many of us share the experience of having learnt in taken-for-granted contexts where the presuppositions for the reasoning were hidden from us (see examples in Wistedt, 1994a, 1994b). Students who are self-reliant may easily overlook such gaps in their prerequisite knowledge. They may feel comfortable anyway, trusting in the promises that all will eventually become clear, that it is possible to go on without being fully informed, that it may not even be possible to gain *"a complete view of the issues"*. But students who belong to minority groups, or students who are less familiar with the cognitive practices of natural science or technology, may feel less confident if they are left alone *"to figure out the fundamentals"*. To refer to matters which 'go without saying' may effectively exclude students who are unaware of the cultural norms, even unaware of the fact that such norms exist (Halldén, 1986, 1990; Bergqvist & Säljö, 1994; Wistedt, 1994a, 1994b). Research has shown that difficulties in discovering and utilising taken-for-granted meta-communicative tools co-varies with achievement level (Miller & Parlett, 1974; Säljö & Wyndhamn, 1988, 1990; Säljö, 1991). Students who are regarded as 'low achievers' are often found to have problems deciphering information of a meta-theoretical kind. Inclusive programmes have to consider such difficulties. In many ways the programmes described in this study have the ambition to do so. The co-operative work forms, the problem-solving approaches and the interdisciplinary practices have one thing in common – they introduce a variation in perspectives and views which may help the students to become aware of knowing as a culturally related phenomena.

Call for a Continued Dialogue

The Government's initiative has started a process of reflection among the teachers involved in the development projects on how to change university teaching to meet with the double challenge of attracting new groups of students to mathematics, science and technology, and to adapt the ways of teaching to meet with these students' demands. In terms of recruitment the initiative has been successful. In terms of stimulating change in the teaching practises it has served as an incitement to try out ideas and to reflect upon educational issues which stretch beyond the projects that received funds.

The initiative comprises five development projects, but the teachers who are involved in these projects do not teach exclusively within the programmes linked to the initiative. Many of them teach other students on other courses as well, and once you have understood and accepted that there are alternative ways of approaching the task of teaching there is, as one of the commentators said, no return. This means that the ideas tried out within the development projects may spread to other programmes and single subject courses as well.

What has been gained from the initiative is therefore the possibility to reflect upon teaching practices which take into account a diversity of experience among students of different backgrounds, and a variation in expertise among teachers from different subject areas. In this study we have provided overviews and in-depth studies with the aim of opening a dialogue on the various ways in which the teachers have realised the programme policies and on the difficulties they have encountered along the way. Their willingness to communicate their experiences in the midst of the developmental process may be viewed as an invitation to a continued dialogue on the possibilities of realising a more inclusive kind of education.

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Högskoleverket Studies 1998:3 S
(Högskoleverkets skriftserie)
ISSN 1400-9498
ISRN HSV-SS--98/3--SE

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