



The Scientific Programming Integrated Degree Program – A Pioneering Approach to join Theory and Practice

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Abstract

While already established in other disciplines, integrated degree programs have become more popular in computer science and mathematical education in Germany as well over the last few years. These programs combine a theoretical education and a vocational training. The bachelor degree course "Scientific Programming", offered at FH Aachen University of Applied Sciences, is such an integrated degree program. It consists of 50% mathematics and 50% computer science. It incorporates the MATSE (M^Athematical and T^Echnical Software d^Eveloper) vocational training in cooperation with research facilities and IT companies located in and nearby Aachen, Jülich and Cologne.

This paper presents the general concept behind integrated degree programs in Germany and the Scientific Programming educational program in particular. A key distinguishing feature of this concept is the continuous combination of theoretical education at university level with practical work experience at a company. In this fashion, students end up being very well positioned for the labor market, and companies educate knowledgeable staff familiar with their products and processes. Additionally students are able to earn two degrees in three years, which is a rare approach for computer science programs in Germany. Therefore, Scientific Programming offers an important contribution towards reducing the shortage in advanced software development and engineering on the German labor market.

Keywords: Scientific Programming, MATSE, Computer Science Education, Integrated Degree Programs

1 Introduction

Outside the university system, professional programs which combine a vocational and theoretical education are well established in Germany. For each of these programs, two learning centers exist: A company, responsible for the vocational education, and a vocational school (*Berufsschule*), which is responsible for the theoretical education.

In 1964 the German board for education (*Deutscher Ausschuss für das Erziehungs- und Bildungswesen, 1953-65*) used the term „dual vocational education and training“ (*Duale Berufsausbildung*) for the first time [2]. Since then, this system has been used successfully throughout Germany for non-university vocational education. At this point it is notable that in Germany this kind of vocational system is of much greater importance than in other countries [3]. Currently, there are over 350 professional programs offered and about 300.000 trainees graduate every year [4], typically after a three year period. Throughout the following, we have often put the German expression in italics next to our English translation for terms specific to these programs, as due to its singular prominence in Germany an authoritative English translation has, to our knowledge, in these cases not been established yet.

Since the mid-seventies another system evolved: integrated degree programs (*Duales Studium*) [1] which combine theoretical education at a university with one of four flavors of practical training [5]:

- Programs integrating vocational training (*ausbildungsintegrierend*)
- Programs integrating internships (*praxisintegrierend*)
- Programs integrating employment (*berufsintegrierend*)
- Programs beside employment (*berufsbegleitend*)

These different types of integrated degree programs share the key idea that university studies are enriched with practical work in companies, but implement this combination in different ways. The differences mainly concern the way universities and companies cooperate, for example whether lectures are held during worktime or in the evening.

In Germany, there is another form of university aside the research university, the University of Applied Sciences. This form of university focuses more on teaching and educating students for the labor market than on research. Therefore, most integrated degree programs are carried out in cooperation with Universities of Applied Sciences. The emphasis in this paper is upon the programs integrating vocational training. In these programs the vocational schools may be replaced or supported by university studies, thus the level of theoretical education throughout the vocational training is significantly elevated.

The bachelor degree course “Scientific Programming” offered at FH Aachen University of Applied Sciences is such a study program integrating vocational training. Its theoretical content consists of 50% mathematics and 50% computer science and the course incorporates the MATSE (**M**athematical and **T**echnical **S**oftware **d**eveloper) vocational training in cooperation with research facilities and IT companies located in and nearby Aachen, Jülich and Cologne.

The intention of this papers is to describe the integrated degree program Scientific Programming. Hence, the following paragraphs describe the structure and the benefits of the program, as well as the program’s quality management.

2 About the Program

The bachelor degree course Scientific Programming emerged from the profession of MaTA (**M**athematical and **T**echnical **A**ssistant), which started as the predecessor of the MATSE back in the 1960s in Aachen, with RWTH Aachen University as main educational facility. At that time it was a

regular vocational training, without university studies, except for the fact that the theoretical part was not offered at a vocational school but instead at the computing center of RWTH Aachen University. The reason for introducing a new profession back then was a growing need for a new type of experts in the research facilities and IT companies located in and nearby Aachen. The development of computer science as a new discipline created new possibilities, also for other sciences, thus specialists were needed which were able to exploit these possibilities. The MaTA program complemented the diploma university programs in computer science, offering an attractive opportunity to young people who were looking for a more hands-on and shorter professional qualification path.

Combining computer science and other sciences, like physics or engineering, the MaTA was successful for nearly fifty years. However, altering legal frameworks and the evolution of Germany's educational system made changes unavoidable, so in 2007 the successor MATSE and also the bachelor degree course Scientific Programming were launched as an integrated degree program.

This transition took into account the high quality of education that was already delivered within the MaTA vocational training, so that the study program Scientific Programming could easily build upon it. Beneficially, the decision to introduce a new integrated degree program fits into a general trend in Germany's educational system, supported by a position paper of the German Council of Science and Humanities (*Wissenschaftsrat*) published in 2013 that recommends establishing more integrated degree programs [1]. One advantage of integrated degree programs over vocational trainings is that successful graduates obtain a Bachelor degree as well, which provides a foundation for further academic advancement if this is desired.

Within an integrated degree program there are several stakeholders, which collaborate closely in the program.

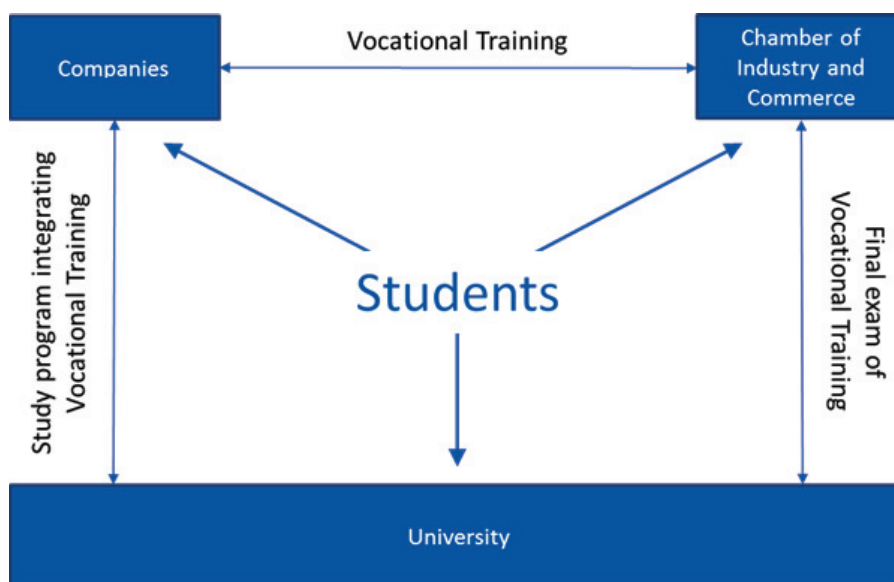


Figure 1: Stakeholders in an integrated degree program

As shown in Figure 1, the stakeholders include:

- the **Companies**, which provide the practical part of the vocational training
- the **Chamber of Industry and Commerce**, which is responsible for the legal regulation and the final examination of the vocational training
- the **University**, which is responsible for the theoretical education and ensuring the scientific aspect of the program

In case of Scientific Programming, the stakeholders are the IT companies and research facilities in Aachen and its surroundings (hereinafter referred to as **companies**), the Chamber of Industry and Commerce in Aachen and FH Aachen University of Applied Sciences.

Since the university supports or replaces the vocational school in an integrated degree program as a theoretical educator, the university has to obey the legal regulations of the Chamber of Industry and Commerce regarding the curriculum. The same holds for the companies, which have to make sure that the practical part of the vocational training also matches the legal regulations. As the theoretical education at the university extends the curriculum mandated by the Chamber of Industry and Commerce, there are some degrees of freedom regarding the additional contents which are taught at the university. To fill these degrees of freedom, the companies and the university have to collaborate to work out a curriculum which fits the companies' needs but is also creditable within the German university qualification framework [6] [7].

The introduction of the MATSE vocational training extended the concept beyond Aachen and spread it throughout Germany. Nowadays MATSEs are also trained in other German cities, for example in Berlin, Munich, Cologne, and, quite recently, in Darmstadt. Altogether, there are more than 500 young people in a MATSE program in Germany, resulting in nearly 150 graduates each year [8].

Nevertheless, the integrated degree program based on a MATSE vocational training is unique to Aachen and its surroundings in Jülich and Cologne, where the main educating facilities are RWTH Aachen University, Jülich Supercomputing Centre and FH Aachen University of Applied Sciences itself respectively. To match a national curriculum for MATSE on the one hand and introduce the possibility to study on the other hand, the main educating facilities and FH Aachen University of Applied Sciences had to work in close collaboration. The result is a study program for Scientific Programming, which enables the students to not only successfully complete their bachelor studies, but also to pass the final exams of the vocational training. Therefore, the syllabus of the MATSE vocational training is included as a subset into the curriculum of the Scientific Programming study program, which was specifically created as theoretical part of the MATSE vocational training. In effect, then, successful students obtain two degrees after three years: A professional degree as well as a Bachelor's degree.

The curriculum of the Scientific Programming study program focuses in equal parts on mathematics and computer science. The mathematical part covers calculus, linear algebra, stochastics and numerical mathematics. The computer science part covers programming, algorithms, software engineering, databases, computer networks and fundamentals of computer systems. The curriculum also includes several elective courses, e.g. parallel programming, mobile applications and operations research. In the 4th and 5th semester there are also two practical reports due, which enable the students to present work they have done in the companies, e.g. special projects, to the university and make this work count for the credits of the study program. The curriculum is shown in Figure 2 and described in detail in [9].

1 st Semester	2 nd Semester	3 rd Semester	4 th Semester	5 th Semester	6 th Semester
Programming in Java		Databases	Practical Report	Practical Report	Bachelor Thesis
IT Basics	Algorithms	Elective Programming	IT Systems	Extracurricular Studies	
Calculus 1		Software Engineering	Computer Networks		Vocational Final Exam
	Calculus 2		Elective Course 1		
Mathematical Basics		Stochastics	Numerical Mathematics	Seminar	Elective Course 3
Linear Algebra 1	Linear Algebra 2			Elective Course 2	Elective Course 4

Figure 2: Curriculum of Scientific Programming

Due to the integration of the MATSE vocational training, there exist some relevant differences between Scientific Programming and regular study programs. In normal university study programs it is common to have lectures spread over all days and times within a week. In contrast, the lectures in

Scientific Programming are held altogether on two days in a week, so that the students have the opportunity to work in the companies for three complete days, training their practical skills. On the two days of lectures the students are required to attend the lectures, and the companies have to exempt the students from work for these days. This approach also matches the recommendations of the German Council for Sciences and Humanities, which recommended establishing more integrated degree programs to fit changing needs on the labor market [1]. The practical work in the companies counts towards credits within the bachelor program, to value that the students gain a deep insight into the company they are working in and also train their practical skills.

Altogether, this combination of vocational training and university studies has advantages over both individual concepts, because the level of theoretical education is higher than in a vocational training but at the same time the level of practical skills that are obtained is much higher than in a university study program.

3 Studying Scientific Programming

Before starting studies in Scientific Programming, a prospective student has to apply at one or more cooperating companies to find a training vacancy. Studying Scientific Programming without a training position is not possible, because the practical work in the educating company is an integral part of the bachelor program. There are over 100 cooperating companies including several university departments in Aachen and surroundings, where a prospective student can start the vocational training. The companies include smaller, local companies but also global players like National Instruments, Atos, Ericsson or Bosch.

Once a training position is found and the training contract is signed, the prospective student has to enroll at FH Aachen University of Applied Sciences. To do this the signed training contract and, as usual, a university entrance certificate, are required. RWTH Aachen University actually has a dual role in this context. The computing center supports FH Aachen University in the theoretical education of the students, while at the same time institutes of RWTH Aachen University also provide the “company” part of vocational training.

Every year about 70% of the new students start right away from secondary school, the other 30% the students previously studied something else or were employed and want to face a new occupational challenge. About 18% of each year’s students are women, which fits into the general trend in the European Union [10]. While this percentage is low, it is considerably higher than the proportion of women that study, for example, computer science at RWTH Aachen University, where in 2015 only about 10% of the new students in computer science were women [11].

On September 1st of each year the students start the bachelor program. For the whole of September the students do not work in the companies, but attend introductory courses in mathematics and programming to harmonize the student’s knowledge in these fields. In October the regular lectures start and so does the practical work in the companies.

A typical schedule for the first semester is shown in Figure 3. As already mentioned, the lectures and tutorials are concentrated on two days to allow for practical work at the company on the other days.

	Monday	Tuesday	Wednesday	Thursday	Friday
Morning	Practical Work	Practical Work	Lectures	Lectures	Practical Work
Afternoon	Practical Work	Practical Work	Tutorials	Tutorials	Practical Work

Figure 3: Example Schedule of the 1st Semester

During the semesters the students attend the lectures, but also work in real-life projects in the companies. The semester closes with exams for each lecture. During semester break the students work full time in the companies, but can take their working holiday (normally 30 work days per year) in that time. Altogether the program is designed to last six semesters.

In the last semester every student has to write and defend a bachelor thesis in order to obtain the bachelor's degree. The topics for these theses are commonly worked out in cooperation with the company where the particular student is educated in and cover a wide range of topics, for example high performance computing, virtual reality or simulation sciences. Also the topics for the other practical projects within the curriculum of Scientific Programming are chosen in close cooperation between university and the companies.

To emphasize the potential scope of a practical project / a bachelor thesis an example is given in the following paragraph:

In 2014 a bachelor thesis was carried out in the high performance computing group at the IT Center in cooperation with the Laboratory for Machine Tools and Production Engineering (WZL), both RWTH Aachen University institutions. The project required mathematics and software development skills and dealt with gear contact analysis. The goal was to compute the forces that are working on the gears in a mechanical system. The approach taken models the gears using a finite element approach. The solution of the sparse linear equations arising in this context can be very compute intensive, so a parallel programming approach was chosen to tackle this issue [12].

The given example shows how students can work in complex projects, applying state-of-the-art techniques from different scientific fields, like mechanical engineering and high performance computing. It also shows that students from Scientific Programming are ideally suited for employment in the area of computational science and engineering, widely considered to be one of the key areas for innovation [13].

After graduating, about 50% of the students pursue a master's degree. Most of these students start either at FH Aachen University of Applied Sciences itself, RWTH Aachen University or Maastricht University. These universities are the logical choices, since they offer a broad range of master programs and are located in or near to Aachen, but also other universities are chosen like Technical University of Munich or the University of Bonn.

4 Benefits

Integrated degree programs in general and Scientific Programming in particular introduce benefits not only for the companies and the students, but also for the universities. These benefits have been widely studied in the last years.

Already during the study program the students benefit from this educational system, because they are paid due to the vocational training in a company [14] [15] [16] [17], which additionally pays also for the tuition at FH Aachen University of Applied Sciences. This, in effect, results in a paid university education, in addition to a professional degree. Additionally there is a mentoring system implemented in the vocational training, which provides each student with a personal mentor, normally an employee from the company, who helps in case a problem occurs, no matter whether it is a problem in a practical project or with the contents of the lectures.

However, the benefits after graduation are even greater. The students report that they feel better prepared for working life as they have already gained working experience during the university studies [17]. The fact that two degrees are acquired, one for the vocational training and one for the university studies [16] [17], also leads to outstanding opportunities on the labor market [14]. In fact, due to the vocational training in a company, most of the students do not even have to apply for a job once they finished their studies [18]. Over 70% of the students stay in the company in which they were educated [19]. If students stay in the company, they also have better career opportunities than other first-time employees, since they already know the company they are working in [17].

But not only the students profit. For the companies it is a significant benefit as well. Over 95% of the companies polled in a study claim that an integrated degree program suits the needs of the companies better than regular vocational trainings or university studies [20]. First and foremost there is no training

period or trainee program necessary for new employees, because they are already familiar with and integrated into the company due to the vocational training [15] [16] [21]. Additionally there is much less staff turnover, because the employees already identify themselves with the company [21] and therefore the costs for staff recruitment decreases [16].

Also the universities benefit from integrated degree programs. According to a study about integrated degree programs, German companies claim that integrated degree programs fill a skill gap existing on the German labor market [22]. Thus the universities are able to educate students in a manner which is tailored to the companies' needs. The universities can also build on the knowledge acquired in the vocational training in their lectures [23], reducing the amount of educational material needed for the lectures, and ensuring practical relevance in the study programs [21].

Altogether, there are many benefits for students, companies and universities. In addition, integrated degree programs are not only beneficial, but in some sense crucial for the economic system in Germany. There is a skill shortage in the IT sector in Germany, which has to be overcome, and integrated degree programs are one important piece of the puzzle [19].

This strategy seems to work, since the number of students who start the Scientific Programming integrated degree program has increased over the last years.

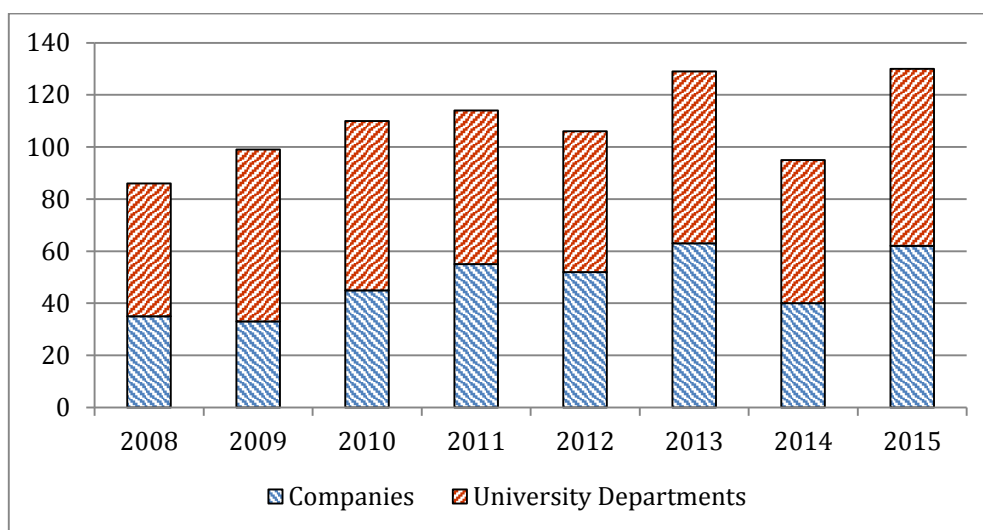


Figure 4: Number of students starting Scientific Programming in Aachen

As shown in Figure 4, slightly less than 90 students started their bachelor studies in 2008, but in 2015 more than 130 students started the program, an increase by nearly 50%. The drop in 2014 is induced by a change in the secondary school system in North-Rhine Westphalia [24]. Additional to the students starting in Aachen there are about 35 students in Jülich and 25 students in Cologne each year. The number of students in Jülich and Cologne have been rather constant over the last years, because of capacity restrictions.

5 Quality Management in Scientific Programming

In the delivery of the Scientific Programming integrated degree program, several stakeholders have to collaborate. In order to maintain a high level of quality, a quality management process has been designed, taking different dimensions of quality into account.

The main tool to ensure the quality of the study program is the accreditation [6]. The German Council of Science and Humanities recommends taking into account the relationship of the learning centers, scientific quality and practical relevance for a successful accreditation [1]. To maintain quality in a continuous fashion, several working groups have been established, which ensure the cooperation between the stakeholders and take care of the development and the interplay of the vocational training and the study program. In addition, a close cooperation between the lecturers and the companies has been established, which assures the practical relevance of the study program. Due to this cooperation, several parts of the study program directly involve the companies, for example bachelor theses or practical projects within the lectures. Some of the part-time lecturers are also employed in one of the cooperating companies, so they can teach state-of-the-art standards and techniques from their daily working life. Beyond the cooperation with the companies, there are also partnerships between FH Aachen University of Applied Sciences and other universities, namely RWTH Aachen University and Maastricht University in the Netherlands, which enrich the elective courses of Scientific Programming with lectures from their own curricula.

The German Council for Science and Humanities defines three more criteria for quality: Contributions of the companies, supporting contributions by the university, and overall costs and financing [1]. The contributions of the company mainly govern the conditions of the vocational training. To provide a suitable vocational training to the students, a company has to fulfil minimum requirements regarding the working environment, especially regarding the scope of projects the student is intended to work in. To make sure students in Scientific Programming find a reasonable working environment, companies have to be acknowledged as a company that is allowed to perform vocational training according to the legal framework supervised by the Federal Ministry of Education and Research [25]. For the Scientific Programming integrated degree program more criteria are defined [26], including, for example, a minimum hardware equipment for the workstation and a qualified mentor for each student, to ensure a level of quality for vocational training which is suitable for the level of theoretical education at university.

Since not only the educating companies are responsible for the level of quality within the integrated degree program, the university may also choose to support the companies in fulfilling their duties. For Scientific Programming, for example, the companies are supported by the university regarding their recruitment process and monitoring of their student's performance throughout the study program. The recruitment is organized centrally and, as a first step, every applicant has to take a recruitment test to make sure that only appropriate candidates are considered during the actual recruitment process. During the study program, the student's performance is monitored particularly closely in the trial period of the vocational training and after examination periods, and the respective company is informed if problems occur. In this case, the student is supported by his or her personal mentor in the educating company, or with tutorials in the university. The administrative processes are certified according to DIN (*Deutsche Industrienorm, German industry standard*) EN ISO 9001 since 2011. These standards are the most extensively used of all the standards issued by ISO (International Organization for Standardization). At both national and international levels, a quality management system certified according to EN ISO 9001 is considered proof of competence and performance capability. Nonetheless, in public educational institutions such a process certification is rare.

A good performance indicator for these support structures is the low dropout rate of the Scientific Programming study program, which is about 17%. This is considerably low, as the average dropout rate for computer science university programs in Germany is greater than 30% [27]. The continuous monitoring of students' performance seems also to have a really big impact on the final exam for the vocational training, which about 98% of the students eventually pass successfully.

As for the last criterion, costs and financing, Scientific Programming students are really quite privileged, as the students do not have to pay tuition fees, which are about 250 Euro per semester, but get a vocational training pay. This tuition fee, which normally would be paid by the students themselves,

includes for example the student ticket for public transportation, which also ensures the students' mobility between university and the educating companies.

Altogether, all the requirements the German Council for Science and Humanities has defined in [1] are met in Scientific Programming in an exemplary fashion.

6 Spreading the Idea

Not only in Germany the MATSE vocational training and the integrated degree program Scientific Programming have become more popular over the last years, but the idea also spread across the borders. In particular, the idea was adapted by Maastricht University. Maastricht University does not offer their KnowledgeEngineering@Work as a program integrating a vocational training due to legal regulations in the Netherlands. Instead the concept was adapted to a program integrating internships [28].

Also outside of Europe the idea of MATSE as a vocational training has attracted attention in Ecuador [29], Russia, Morocco and Spain. Especially for emerging and developing countries, the concept of MATSE is interesting, because vocational training can be carried out without requiring an expensive infrastructure: A recent laptop with open source software is sufficient. In this fashion, vocational training supports in particular startup or small companies, which can achieve economic success without huge investments, but a good business idea and well educated employees.

7 Conclusion

The integrated degree program Scientific Programming offered at FH Aachen University of Applied Sciences, which integrates the MATSE vocational training, has been successfully established following the recommendations of the German Council of Science and Humanities. The graduates have very good opportunities on the labor market; most of the time they actually continue employment in the company that provided the vocational training. In addition, also the companies benefit from participation in the integrated degree programs, as it allows them to satisfy a growing need in the recruitment of their labor force. Therefore, the integrated degree program Scientific Programming, which currently is a unique educational offer at FH Aachen University of Applied Sciences, is a forward-looking educational program which complements traditional educational paths. It offers a higher level of theoretical education in comparison to just vocational training as well as more practical training than university education.

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