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Educating tomorrow's chemists

Reiner Salzer

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"Peace Through Chemistry" is the title of a lithography by Roy Lichtenstein [1]. This work and its title attracted my attention when I recently visited an exhibition of modern art. I can hardly imagine finding a current piece of art, which professes a similar gratitude and expectation to chemistry. Our society has changed so much since 1970, the year of origin of "Peace Through Chemistry." To what extent did these changes in society influence our study programs? Yes, we now teach advanced instrumental analysis, quantum chemistry, nanochemistry, and much more. But are such added fundamentals sufficient to prepare young people for the new challenges in modern societies?

A Presidential Task Force of the American Chemical Society (ACS) concluded in their brochure "Innovation, Chemistry, and Jobs—Meeting the Challenges of Tomorrow" on page 33: In chemistry departments (although not in chemical engineering and other fields), "professors' words and actions promote the idea that basic research, and a career in academe, are the highest aspirations for topnotch students" [2]. How do such topnotch students themselves look at their status [3]: "As researchers, we are trained to work within a rational and methodical framework. But when it comes to running our labs and managing people, we have to rely on our gut feelings, our limited know-how from mentoring a few students, or our observations of our previous advisers. We can often feel ill-prepared. Starting an academic lab is like launching a small business. But does scientific training really prepare us for success? As a young investigator just over a year into my job, I feel pressure."

Many young scientists look at working in industrial research as very innovative and not much different than in many academic labs. There are long-term industrial project goals in numerous areas—pharma and medical genetics, biofuels, materials, and others that push discoveries as much as academia does. The perspectives of how scientists look at industrial and academic research might be somewhat different in different parts of the world, but success requires similar skills and attitudes everywhere. My perspective is certainly a European one. In order to achieve a certain balance, I chose most of my references from outside Europe.

In the history of analytical science, the deciding incentive for the birth of a novel and leading analytical technique often came from academic research. The self-conception of research and development in academia and industry is and must be significantly different. Schlemmer described this and listed some of the substantial differences in an earlier contribution to this column (Table 1 and [4]). Whereas academic research has to be predominantly interested in fields where white spots on the scientific map promise a fruitful research playground, most industrial topics exploit further developments of existing products rather than elaboration of a new procedure. These differences will always remain. The challenge consists in providing gateways from either side according to their current needs. The above-mentioned ACS Presidential Task Force emphasizes for the academic part: If universities are indifferent to what society needs, society may reciprocate that indifference. Educating the next generation of scientists and engineers to recognize and consider opportunities that have impact on society is essential for future cultural changes in the chemical enterprise.

Current professional requirements

No doubt, the attributes needed in modern chemical industry have changed. From the perspective of industry, however, the curriculum at most traditional universities does not necessarily reflect these new dynamics [5]. According to this view,

This paper is dedicated to Professor Günter Gauglitz on the occasion of his 70th birthday.

R. Salzer (✉)
Bioanalytische Chemie, Technische Universität Dresden,
01062 Dresden, Germany
e-mail: reiner.salzer@tu-dresden.de

Table 1 Differences between academic and industrial R & D [4]

Character	Academia	Industry
Incentive	Scientific interest publication	Market needs unique offering
Invented device	Research tool	Product
Technology	Selected hand-crafted components	Commercially available parts
Success criteria	Outstanding results from limited number of experiments	Long-term stability ruggedness of target performance
Database	Fine-tuned unique specimen	Average-performing system
Appearance	Breadboard	Designed product
Economy	–	Binding cost specification

curricula show deficits in the development of nontechnical skills. Although a strong foundation in the fundamentals and a diverse knowledge of cutting-edge research are important, candidates can further differentiate themselves by rounding out their nontechnical skills. The latter are sometimes also called transferable skills, generic skills, or soft skills. Recently, we even observe a tendency to split nontechnical skills into "soft skills" and "entrepreneurial attitude" (Fig. 1). Entrepreneurial attitude is often misunderstood as one's own accord to launch a new company. Instead, entrepreneurial attitude is characterized by initiative, pro-activity, independence, and innovation in personal and social life, as much as at work. It also includes motivation and determination to meet objectives, whether personal goals or aims held in common with others, including at work. This definition is quoted from the recommendation of the European Parliament and of the Council of the European Union on key competences for lifelong learning [6].

Though the traditional workplace still holds influence over an employee's attitude and mindset, entrepreneurial attitude is increasingly becoming a corporate necessity and a mandatory part of an employee's job description [7]. Promotion of entrepreneurial attitude may appear to be of peripheral importance to universities committed to advancing science and humanities, but entrepreneurs can anchor intellectual endeavors in reality by deploying the practical output of knowledge. Given the role of entrepreneurship in economic growth and social progress, the training of entrepreneurs can be deeply connected to public service, central to the mission of universities [8].

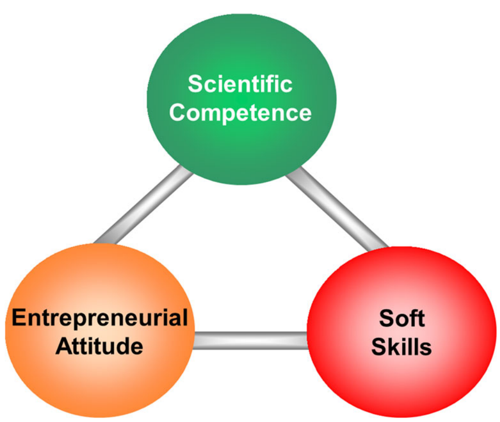

Fig. 1 Current requirements for all professionals, not only for entrepreneurs

Beyond problems with nontechnical skills, representatives from academia, like George Whitesides as chemist with the distinctly highest h-index worldwide [9], even identify deficits in the science part of our study programs. He sees contemporary chemical industry fully embedded in society, whereas academic chemistry appears increasingly incurious and risk-adverse. For the future, he locates chemistry's best intellectual properties outside its historical boundaries. Tomorrow's chemists need to work at integrating many disciplines. This requires changes in chemistry's coursework, in order to prepare our graduates for the job market [10]. Matching skills and market demands is the best way to fight graduate unemployment. Is there a disconnect between how we currently train scientists and the actual employment opportunities available for them [11]? In the USA, the unemployment rate for those looking for work was 12.6 % in 2012 [12]. In comparison, unemployment rates are much higher for other countries, not only in southern Europe [13]. In a mobile world. we need to prepare all graduates for an increasingly competitive job market.

People who behave like an entrepreneur while working within a large organization are nowadays called intrapreneur [14]. This term was coined in 1978 by Gifford and Elizabeth Pinchot [15]. It refers to initiatives of employees in organizations to undertake something new, without being asked to do so. Academic research about intrapreneurship started in the mid-1980s. Often quoted is an interview given by Steve Jobs, Apple's former Chairman, in September 1985 in Newsweek: "The Macintosh team was what is commonly known as intrapreneurship—only a few years before the term was coined—a group of people going, in essence, back to the garage, but in a large company." Today, intrapreneurs are seen as inside entrepreneurs who follow the goal of the organization. They produce social capital in addition to economic capital. As more and more employers in the private as well as in the public sector assess entrepreneurial attitude or intrapreneurship when evaluating employees, we need to provide our graduates with such skills.

M.Sc. and Ph.D. theses are good examples for the benefit of entrepreneurial attitude both on the side of the supervisor and on the side of the Ph.D. student. A Ph.D. curriculum is primarily research oriented, not just another cycle of lectures. How can the completion of the Ph.D. project be ensured within 6–8 semesters? Nobody would establish a *business plan* for a common Ph.D. project, but a sound *project plan* would be very helpful. Several components of a project plan for research are more or less identical to those of a business plan: draw up work packages and a flow chart, define milestones, and device a plan B in case you will not meet your milestones. Ph.D. students should insist on establishing this kind of project plan. It will certainly contribute to a short duration of the Ph.D. project without losing research quality. The German Chemical Society regularly surveys the duration of Ph.D. projects. The median for all evaluated German universities did not change significantly between 2010 and 2012. The highest values (11.8 semesters) and lowest values (5.1 semesters) for the median of individual universities remain widely separated [16], probably a distinct disadvantage for graduates from some universities in the competition for a job.

Actually, only 11 % of European citizens are entrepreneurs, 45 % would like to be their own boss if they could, whereas in the USA this proportion is 55 %. Europe lags behind the United States in terms of entrepreneurship. This lack of entrepreneurial drive is not due to the overall dislike of entrepreneurship in particular countries but rather the result of concrete structural, administrative, and educational factors that need to be tackled [17]. In the European Higher Education Area (EHEA) the Bologna Process is intended to accept the challenge [18]. But too many faculty apparently see the Bologna Process only as technical transition to the three-cycle educational system (B.Sc./M.Sc./Ph.D.).

Issues in employability

Is it true that our training systems remain focused on producing independent research scientists and do little to prepare students for science careers away from the bench? Do we leave our graduates with the decision between an "honorable" career in academia versus an "alternative" career in the private sector [19]? The private sector offers a variety of jobs other than research. For analytical chemists, this includes, for example, safety assessment, regulatory affairs, clinical science, project management, alliance management, business development, technology transfer, marketing, sales, science, and patent law. Faculty members often have little experience with industry and, in particular, with most of the job categories just mentioned. Moreover, when we talk about the requirements in chemical industry, we often look at large enterprises. We should remind ourselves that in many countries, most of the chemical companies are small enterprises (Fig. 2). Small enterprises usually require other competences for their employees in addition to research experience. These nontechnical competences have to be developed at all degree levels.

Attributes of entrepreneurial attitude are personal, social, and management skills. The Chemistry Quality Eurolabel® framework [21] does not yet explicitly mention the term entrepreneurial attitude but describes the abilities and competences to be developed during the three cycles of the study program. In this description, closely related to entrepreneurial attitude is the student's level of responsibility. The requirements for the respective Eurolabels® are:

> B.Sc. graduates will have developed those learning skills that are necessary for them to undertake further *study with a sufficient degree of autonomy.*
> M.Sc. graduates will have developed those learning skills that will allow them to continue to *study in a manner that may be largely self-directed or autonomous*, and to take responsibility for their own professional development.
> Ph.D. graduates can be expected to be able to *promote, within both academic and professional contexts, scientific and technological advancement* in a knowledge-based society.

The required level of responsibility grows systematically from cycle to cycle. To which extent do our current curricula

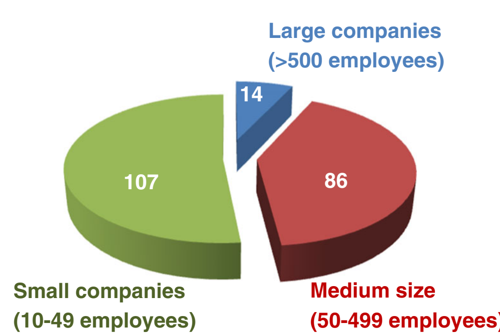

Fig. 2 Quantities of German Chemical Companies according to their sizes in 2012 [20]

satisfy these quality standards? The recent survey by the American Chemical Society provides a clue [12]. When asked if their training and education is commensurate with their job, only 70.0 % of bachelor's degree earners agreed, compared with 84.4 % and 90.3 % of master's degree earners and Ph.D. holders, respectively. Restricted autonomy in bachelor programs is certainly one of the reasons for the lower satisfaction of these graduates. Incorporation of problem-based or project-based laboratories in courses—not only in analytical chemistry—can be an improvement as these types of laboratory experiences require students to independently work through the steps necessary to answer a real-world question [22]. But a greater solution requires thorough mental changes, not just technical or administrative reforms [10]. With respect to the policy of university departments, student-centered learning seems to be one of the greatest challenges.

Conclusions for education

Employability is not an abstract term. The economic development requires competitive employees. Promotion of interdisciplinary training and the development of transferable skills are requirements of the wider employment market.

The development of soft skills must not be seen as competition to the development of scientific competence. Transferable skills can best be developed together with scientific competence and vice versa. A strong foundation in fundamentals is always required, but more emphasis should be placed on the job world in the near future. Quality assurance and management is not an issue in chemical production anymore. Interdisciplinary education and research have to play a larger role in our curricula.

Among the soft skills particularly emphasized by non-academia are: team player, leading employees (in university: students) to success, communication, and interpersonal understanding. Such skills cannot be developed if the graduate completes her/his thesis in an isolated laboratory. Student-centered learning requires the incorporation into a team, for example, a Ph.D. school. Last but not least, I want to mention the necessary development of the student's skill to handle ethical challenges.

Some aspects of entrepreneurial attitude are already hidden in many curricula. Students are expected to think in processes and to plan their projects carefully (time management). What is often missing is cost management. Project-based laboratories sometimes include aspects of cost management. This is an excellent opportunity to develop this kind of skill.

An outstanding example for early consideration of soft skills in his educational activities is Professor Günter Gauglitz, one of the Editors of ABC. Throughout his career, he considered teaching not as his duty but as inspiration for students. Since several years ago, Günter Gauglitz took an active part in several teaching developments. He is supporting the education of undergraduate and graduate students, simulating the processes on expensive lab instruments, and developing generic skills at all levels of tertiary education. He was among the first to use e-learning tools in a reasonable way, and he provided these tools to others (e.g., [23]). His courses impart basic knowledge, while the focus is on applications. Thanks to his widespread research interests, he acquired numerous national and international interdisciplinary research projects. This provides his students the opportunity to choose from a variety of topics. Günter's theoretical and practical courses can be adapted to the individual interests of the participants. His students are excellent examples for graduates with well-developed scientific and transferable skills. His pupils are currently found at all levels in industry, administration, and academia. This contribution is dedicated to him to acknowledge his achievements as university teacher, analytical scientist, open-minded colleague, and friend.

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Reiner Salzer retired as Professor of Analytical Chemistry at the Technische Universität Dresden, Germany, in 2007. He obtained his academic degrees from the University of Leipzig, before taking up his appointment at the TU Dresden. His main scientific interests include molecular monitoring for early diagnosis of diseases, integration of biologically active functions into polymers, and electronic media in university education. He is a member of the Norwegian Academy of Science. Professor Salzer is a long-time advisory board member for analytical and spectroscopic journals. He served as President of the Division Analytical Chemistry of the German Chemical Society, and is National Delegate to the Division of Analytical Chemistry of EuCheMS, where he is Head of the Study Group Education.Currently, he is Chairman of the ECTN Label Committee for the quality labels Chemistry Eurobachelor®, Chemistry Euromaster®, and Chemistry Doctorate Eurolabel®.