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Evaluation of the Chemistry Knowledge of Students Entering the ETH Zurich with a Moodle Quiz

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Abstract: The basic chemistry knowledge of first-year students in the disciplines *Chemistry*, *Biology*, *Pharmaceutical Sciences*, and *Health Sciences and Technology* has been evaluated within the first three weeks of the Fall semester with a Moodle-based quiz at ETH Zurich. It consists of 37 small problems testing the knowledge that ETH students entering the lecture courses *General Chemistry 1 (Inorganic Chemistry)* (AC1) and *Organic Chemistry 1* (OC1) should ideally have. An initial set of questions was developed by Bernhard Jaun (ETH Zurich) in 2007, it was combined with questions from an evaluation created in 2015 by Markus Müller (secondary school II teacher). The results of a total of 925 students who took part in the 2016 and 2017 evaluations are presented. It was found that 80% of the students of Chemistry, Chemical Engineering and Interdisciplinary Natural Sciences (AC1 course) and 70% of the students of Biology, Pharmaceutical Sciences, and Health Sciences and Technology (OC1 course) scored ≥60%. Students who took the focus course (*Schwerpunktfach*) *Biology and Chemistry* at the SEK II level (Swiss school system) performed on average 13–18% better and with a smaller standard deviation than other students. No significant differences were observed with regard to gender or the region in which the qualification for university entrance was obtained.

Keywords: Chemical education · Chemistry knowledge · Evaluation · First-year students · Moodle test

Markus Thomas Müller (born on 16 March 1967), Matura Type B in Frauenfeld (1986), graduated in environmental sciences as a water chemist at ETH Zurich (1992). While teaching biology and chemistry for the first time, he obtained a master degree in teaching (*Höheres Lehramt*) in 1995. In the same year, he started his PhD thesis at the EMPA, St. Gallen, and EAWAG, Dübendorf, under the supervision of Dr. Urs Baumann, Dr. Beate Escher and Prof. Alexander J. B. Zehnder. In 2000, he completed his thesis 'Anaerobic Biodegradation and Toxicity of Alcoholethoxylates' while already working for Millipore Corp. in Switzerland and Strasbourg. Back in Switzerland, he returned to teaching chemistry. In 2004, he pursued a Master in Management and Technology (MAS MTEC) at the ETH. From 2015 to 2016 he enjoyed a sabbatical in the group of Antonio Togni, ETH, with one focus on the interface between secondary school II and university, and another one on the first-year chemical education at ETH. Together, they initiated the foundation of the Division of Chemical Education at the Swiss Chemical Society and organised its first symposium 'Future of Chemical Education'. Currently, he is working as chemistry teacher at the Kantonsschule Frauenfeld.

1. Introduction

1.1 *General Introduction*

It is a common complaint among teachers that students forget what they have learned soon after a test[1] or over the year. It is also a statement often heard from chemistry professors when they talk about what students have learned at school before they enter university. In 1989/1990, Saldanha *et al*. investigated the quality of the students' theoretical knowledge in chemistry before they started studying biochemistry. The obtained results confirmed a clearly insufficient chemical background, in spite of the high scores achieved by the students in chemistry and other science subjects in the admission assessment.[2] The early identification of students with a potential or risk to fail the chemistry exams in their first year at the university have been investigated by Potgieter *et al*. at the University of Pretoria.[3] They found three variables, *i.e.* the prior performance in *mathematics* and *physical science*, and the extent of overconfidence expressed as the ratio between expected and actual performance in a chemistry entry test at the beginning of the semester. These variables were shown to be significant predictors for increased risk of failure in the first semester course in General Chemistry (CMY 117).

Moodle courses offer the opportunity for self-assessment quizzes with the goal to increase the students' self-confidence by means of a self-evaluation-based training process. This was recently described by Schettini *et al*.[4] They evaluated three academic years of general and inorganic chemistry for first-year students at the University of Camerino (Italy). The general satisfaction of the students participating in Moodle-based self-assessments, evaluated in a Moodle survey, was greater and in comparison to the previous year, they found an increase of 11% of students passing the final exams and a positive correlation between the time spent on the e-learning platform and the achieved mid-term scores. The authors also nicely reviewed different pedagogic and didactic aspects of Moodle-based learning.

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The present study deals with the evaluation of the chemistry knowledge of students at the time when they start their studies in various ETH programs, *i.e.* Chemistry, Chemical Engineering, Interdisciplinary Natural Sciences, Biology, Pharmaceutical Sciences, and Health Sciences and Technology. It looks at a possible correlation, amongst others, with their prior education at secondary school II (SEK II). It was carried out in the general frame and spirit of the HSGym project,[5] where the focus lies on an improvement of the interaction and the dialogue between university (**H**och**S**chule) and high school (we use throughout the term high school to mean secondary school level II: SEK II, **Gym**nasium).[6] Furthermore, the focus of our project addressed a possible improved transition from the students' perspective. Part of our results have been presented earlier within the Chemistry Group at the HSGym symposia (2015–2017) and at the Conference of the Chemistry Teachers of the Canton of Zurich (2016).

1.2 *Development of the Moodle-based Self-assessment 'Standortbestimmung'*

The self-assessment *Standortbestimmung* of this study is the result of a merger, in 2016, between a quiz composed by B. Jaun after the setup of a first ETH Moodle course in Organic Chemistry in 2007 (*Organic Chemistry 1 for students of Biology, Pharmaceutical Sciences, and Health Sciences and Technology*,[7] 'OC1') and another one, devised by two of us (MM and AT) in 2015 in the context of the Moodle course Allgemeine Chemie 1 (Anorganische Chemie) (*General Chemistry 1* (Inorganic Chemistry) *for students of Chemistry, Chemical Engineering and Interdisciplinary Natural Sciences*,[8] 'AC1'). MM's experience as a high school teacher helped to make sure the questions represented a well-balanced choice covering the main chemistry topics taught at the high school level. One advantage of having a unified quiz is the larger sample and the broader variety of candidates available, which makes a statistical analysis of the data more interesting and meaningful.

1.3 *Test Groups Evaluated with the Standortbestimmung*

The *Standortbestimmung* was conceived for two clearly different groups of students. The AC1 lecture[8] is attended by first-year students from the study programs *Chemistry*, *Chemical Engineering* and *Interdisciplinary Natural Sciences*, for whom chemistry is a major subject. On the other hand, the OC1 course[7] is taught for the study programs *Biology, Pharmaceutical Sciences,* and *Health Sciences and Technology*, for whom chemistry is a secondary subject.

In this context, it may be worth mentioning that the AC1 course is attended by about 180 and the OC1 by about 500 students per year. The harmonized test is available since Fall 2016 and – participation being voluntary – has been completed by a total of 925 students in 2016 and 2017. To ensure that the results actually reflect the knowledge that the candidates acquired at high school and not as university students, it has to be taken within the first three weeks of the semester.

1.4 *Objective of the Standortbestimmung*

It is important to mention that the *Standortbestimmung* constitutes a mere self-evaluation and counts in no way as graded semester performance. Its main purpose is to make the students realize right at the beginning of their studies whether the basic chemistry knowledge, which is expected from them at this point, has been covered by their high school curriculum and, if so, whether they can still draw on it. The assessment should, therefore, help the students to identify possible gaps in their knowledge and allow them to fill these as soon as possible, thereby making the start into the chemistry courses most successful.

In the AC1 course, the results of the test are made available to the teaching assistants of the weekly exercise sessions. From a pedagogic viewpoint, this should enable them to keep a weather eye on the students who did not perform so well and to specifically address their knowledge gaps. This concept is continued over the entire first semester with Moodle-based online exercises in AC1. In OC1, a broad variety of online quizzes, which cover the main topics of the course, is offered in addition to the weekly exercise sessions. Furthermore, in the middle and at the end of the semester, the students are prompted to take part in an online self-assessment which, again, does not count as graded semester performance but otherwise has the format of an exam.

Although a statistical analysis of the results was not the primary motivation for the *Standortbestimmung* (*vide supra*), it is worth taking a closer look at the available data and discussing a number of aspects that are relevant to the transition from high school to university. The political discussion about the value of the '*Matura*' (general qualification for university entrance) and the free access to university often lacks empirical data. By examining the results of our assessment, we do not intend to support the advocacy of standardization, instead, we want to raise awareness of the various concerned parties for the topic in order to enable the students to have the best possible start into their studies and to successfully accomplish the basic chemistry courses.

When analyzing the results of the *Standortbestimmung*, we focused on the following questions:

1) How well are the students prepared in chemistry when they start an ETH study program in which this subject is fairly to highly relevant? The free access to university for high school graduates leads to the question as to whether the *Matura* is still a valid ticket. One often hears the general complaint that the students are insufficiently prepared for university.
2) Is there a difference in the performance of students who had chosen *Biology and Chemistry* as focus subject (SF: *Schwerpunktfach*) at high school or *Chemistry* as an elective course (EF: *Ergänzungswahlfach*) as compared to those who attended the general chemistry course (GL: *Grundlagenfach*)?
3) Is there a difference in the performance of the students of the AC1 course (*Chemistry*, *Chemical Engineering* and *Interdisciplinary Natural Sciences* programs) and those of the OC1 course (*Biology, Pharmaceutical Sciences,* and *Health Sciences and Technology* programs)?

2. Method

Most of the questions of the *Standortbestimmung* have been used and optimized in earlier quizzes of the OC1 and AC1 courses. They were analyzed and selected according to their level of difficulty, relevance and complexity, if necessary adapted, and finally grouped according to the different topics of the high school curricula.

The *Standortbestimmung* was embedded in the AC1 and OC1 Moodle courses and could be taken any place, any time within the first three weeks of the semester. Participation was optional, and the test was open book, open end.

The first eight questions inquired about the students' personal background, *e.g.* the time span between the completion of the Matura and the start of the studies at ETH (question no. 1), the time elapsed since they had their last chemistry class (no. 2), gender (no. 4), canton/country of origin (no. 5), school profile (no. 6) that were chosen by the students while at high school (see Table 2 and Fig. 2) and a self-appraisal of their current chemistry knowledge (no. 8).

The final question (no. 46A) asked for a self-appraisal of the performance just delivered in the *Standortbestimmung*.

The chemistry questions (nos. 9–45) were grouped according to different topics of the high school chemistry curriculum (Table 1). The achieved total scores (60 points maximum) were normalized to a scale from 0 to 10 (Tables 3, and Tables S3, S4 and S5 in the Supplementary Information).

Table 1. Topics covered by the different questions of the Standortbestimmung, absolute maximum scores (points) for the corresponding groups of questions, and normalized maximum scores (sum amounts to 10).

Topic of questions	Question no.	Max. score (pts)	Normalized max. score
Atomic structure, periodic table, molecules, compounds	9 to 14	8	**1.33**
Stoichiometry and calculations	15 to 20	8	**1.33**
Molecules, salts, metal complexes	21 to 24	8	**1.33**
Acids and bases, pH, pKa	25 to 29	9	**1.50**
Redox chemistry	30 to 35	9	**1.50**
Thermodynamics, kinetics, equilibria	36 to 40	11	**1.83**
Organic chemistry	41 to 45	7	**1.17**
Total	**37**	**60**	**10**

Table S1 in the Supplementary Information shows some sample questions from different sections (*cf.* Table 1) of the *Standortbestimmung*.

3. Results

A total of 925 students completed the *Standortbestimmung* in 2016 and 2017. The answers to the non-chemistry questions (personal background, self-appraisal; nos. 1–8, 46A) of the test are presented in Table 2.

The male:female gender ratio differs significantly in the two courses; it amounts to 60:40 in AC1 and inverts to 40:60 in OC1. About 45% of the AC1 and OC1 students started their studies at ETH immediately after passing the *Matura*, another 45% one year later. Between 50% and 60% of the students had a curriculum with a scientific profile at high school: 40–46% with a focus on biology and chemistry, 9–15% with a focus on mathematics.

Asked for a self-appraisal of their chemistry knowledge (question no. 8, Table 2) the AC1 students generally rated their proficiency higher than the OC1 students. The category *good* or *very good* was chosen by 31–32% of the AC1 students vs. 19–22% of the OC1 students. About half of all students (46–52%) considered their chemistry knowledge as medium, whereas 16–21% (AC1) and 27–33% (OC1) rated it as poor or very poor.

These results parallel the answers to another self-appraisal question (no. 46A, Table 2), asking the students for their performance in the *Standortbestimmung* right after finishing the chemistry-related questions: In 2016 and 2017, a mere 45% and 56%, respectively, of the AC1, and only 26 % and 27 %, respectively, of the OC1 students estimated to have reached a score between

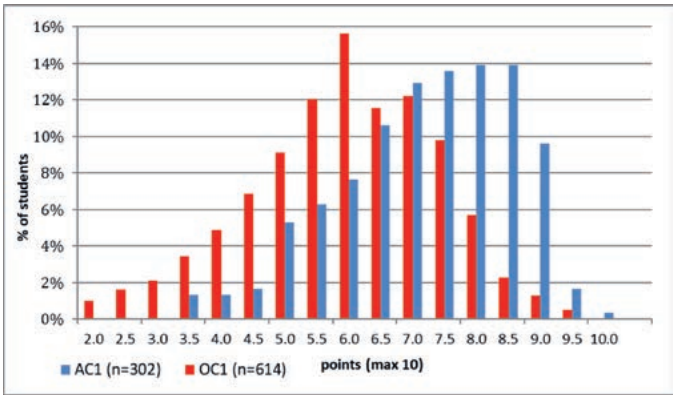

Fig. 1. Comparison of the scores attained by AC1 (n = 302; chemistry as a primary subject) and OC1 (n = 614; chemistry as a secondary subject) students (*Standortbestimmung* 2016 and 2017). Students who solved <15 out of 37 problems and reached <2 points out of 10 have not been included. 90% of the AC1 and 72% of the OC1 students reached ≥5.5 out of 10 points. n = number of participants.

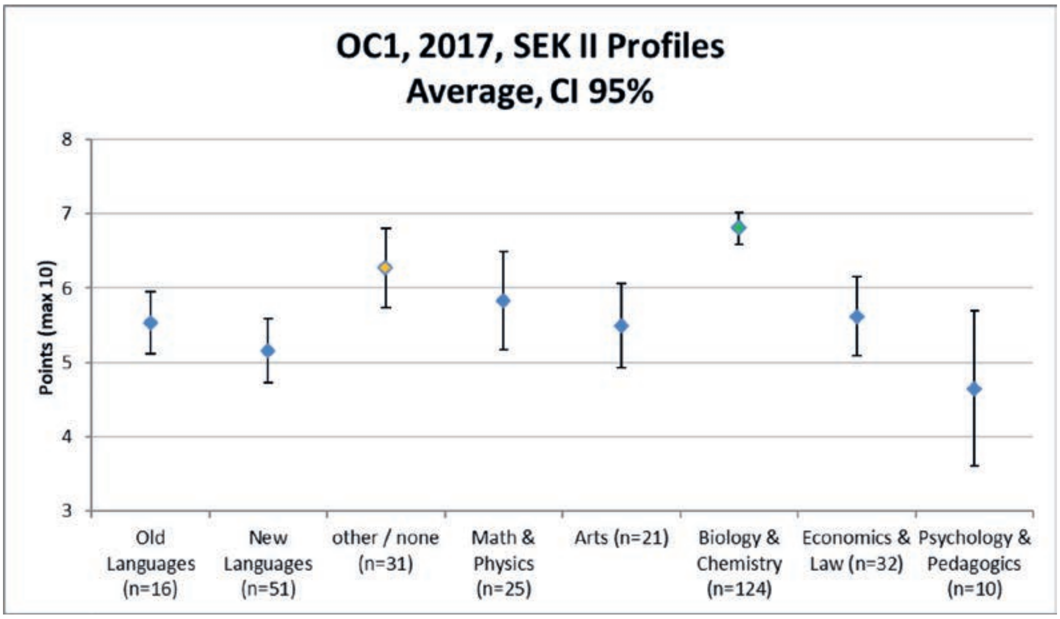

Fig. 2. Scores of the OC1 students (2017) with different high school profiles: Averages are normalized to a maximum of 10 and displayed with 95% confidence intervals, n = number of participants

Table 2. Answers to the non-chemistry questions of the Standortbestimmung (2016 and 2017). AC1 course: students of Chemistry, Chemical Engineering and Interdisciplinary Natural Sciences; OC1 course: students of Biology, Pharmaceutical Sciences, and Health Sciences and Technology.

		2016		2017	
Quest.		AC1	OC1	AC1	OC1
no.	**Number of students**	169	310	139	307
4	**Gender**				
	Male	61%	41%	66%	34%
	Female	39%	59%	34%	66%
1	**I passed the *Matura* … ago**				
	0 – 0.5 year	46%	42%	42%	43%
	0.5 – 1 year	16%	20%	19%	18%
	1 – 1.5 years	25%	23%	29%	20%
	≥2 years	10%	13%	9%	18%
2	**I had my last chemistry lesson … ago**				
	0.5 year	45%	36%	47%	33%
	1 year	14%	15%	9%	12%
	1.5 years	26%	19%	26%	28%
	≥2 years	12%	29%	17%	27%
6	**School Profile (SEK II)**				
	Biology and Chemistry	46%	42%	46%	40%
	Mathematics	10%	9%	15%	9%
	Old Languages (Latin, Greek, ...)	11%	11%	7%	5%
	New Languages (Spanish, Italian, ...)	6%	9%	7%	16%
	Business and Law	8%	9%	9%	10%
	Artistic	4%	6%	1%	7%
	Pedagogic	1%	1%	0%	3%
8	**Self-appraisal of current chemistry knowledge**				
	Very good	3%	2%	3%	1%
	Good	28%	17%	29%	21%
	Medium	51%	48%	46%	52%
	Low	12%	27%	20%	22%
	Very low	4%	6%	1%	5%
46A	**Self-appraisal of performance in the *Standortbestimmung* quiz**				
	80–100% of the questions solved correctly	11%	5%	15%	4%
	60–80%	34%	21%	41%	23%
	40–60%	23%	35%	33%	40%
	<40%	15%	37%	10%	33%

60% and 100%. At the other end, 10% (2016) and 15% (2017) of the AC1 students and as much as 33% (2016) and 37% (2017) of the OC1 students assumed they had solved less than 40% of the problems correctly.

Fig. 1 shows the test performance of all AC1 and OC1 students of 2016 and 2017. About 90% of the AC1 and 72% of OC1 students, who had solved the test, attained a score ≥5.5 out of 10 points.

When we compare Table 2 and Fig. 1, it is obvious that many students underestimated their performance in the self-assessment (question no. 46A, see above and Table 2). We therefore compared the answers of the OC1 students for question 46A more closely with their actual performance in the *Standortbestimmung* 2017: 44% of the OC1 students appraised their performance in the Standortbestimmung within a range of ±10% of their actual score, whereas 51% underestimated their score by more than 10%. Only a few students, namely 4.5% (n = 14), overestimated their score by more than 10%, and most of them (n = 13) achieved less than 3 out of 10 points.

OC1 students reached an average score of **6.21** out of 10 points (number of participants n = 614, standard deviation = 1.46, 95% confidence interval = 0.116) while AC1 students, who study chemistry as a primary subject, scored significantly higher with an average of **7.43** points (number of participants n = 302, standard deviation = 1.33, 95% confidence interval = 0.151).

The 2017 data set of the OC1 students (n = 310) was analysed in further detail as a function of i) the high school profile, ii) the canton or country where the *Matura* was obtained and iii) the gender. The **different high school profiles** did not result in significant performance differences (Fig. 2 and Table S2): A majority of students reached an average score between 5 and 6 (out of 10). A notable exception are the students with a natural science profile (*Biology and Chemistry*) who attained a significantly higher score (6.8 points).

The canton or country where OC1 students obtained their *Matura* ('origin of Matura') did not have a discernable influence on the performance in the *Standortbestimmung* 2017 (Fig. 3). Also, no significant gender effect could be detected (Fig. 4). This is consistent with the results presented in Fig. 6 and also with earlier data from the AC1 course obtained in 2015 and 2016 (data not shown here).

Table 3 lists the attained average scores for each question of the *Standortbestimmung* 2016. For better comparability, the scores have been normalized to 1 (equivalent of 100%). At the same time, the Table provides an overview of the topics treated in the various questions.

Table S3 provides a comparative overview of the normalized average scores reached in each question of the 2017 *Standortbestimmung* by AC1 students (chemistry, chemical engineering and interdisciplinary natural sciences, n = 137) and the different sub-groups of OC1 students (biology (n = 70), health science (n = 151) and pharmaceutical sciences students (n = 84)). The results presented in Table 3 and Table S3 show that the students had particular difficulties (low average scores, high standard deviations) with questions no. 20, 24, 29, 32, 35–37 and 44. It is therefore important to note the following:

Question no. 20: Intricate stoichiometric question, where the students have to find their way through a host of physical data and choose the right ones to solve the problem. *Question no. 24*: It is about metal complexes with organic ligands. This topic is normally not a part of the high school curriculum, but of the specific chemistry course (*Schwerpunktfach*). *Question no. 29*: The correct interpretation of a titration curve is usually not an easy task. *Questions no. 32 and 35*: Use of the correct terminology to describe a redox reaction and the interpretation of the processes taking place in a galvanic cell. *Question no. 36*: Application of the principle of Le Châtelier to a given reaction. *Question no. 37*: Calculation of a concentration using the law of mass action. *Question no. 44*: Carotene and the absorption of light; this is normally not a part of the high school curriculum, but of the specific chemistry course (*Schwerpunktfach*).

4. Discussion

It should be noted that the two student cohorts of AC1 and OC1 clearly differ in the intensity and depth with which most of them will study chemistry at ETH (*cf.* section 1.3.). This explains the differences seen in Fig. 1 to a large extent and has to be kept in mind for the following discussion.

4.1 *How good is the students' chemistry background, when they start their studies at ETH?*

The results of the Standortbestimmung show that both AC1 and OC1 students have a good chemistry knowledge in most of the topics covered by the general high school curriculum. The lowest scores were attained in problems dealing with equilibria, thermodynamics, and kinetics (questions no. 36–40, Table 3 and Table S3). The average scores for the different sections of the self-assessment reflect this outcome for all sub-groups of students (Table S4).

Fig. 8 (and Table S5 in the Supplementary Information) displays a comparison of results obtained in different sections of the *Standortbestimmung* by OC1 and AC1 students in 2016 and 2017. The average total score was 61–63% and 71–76% for

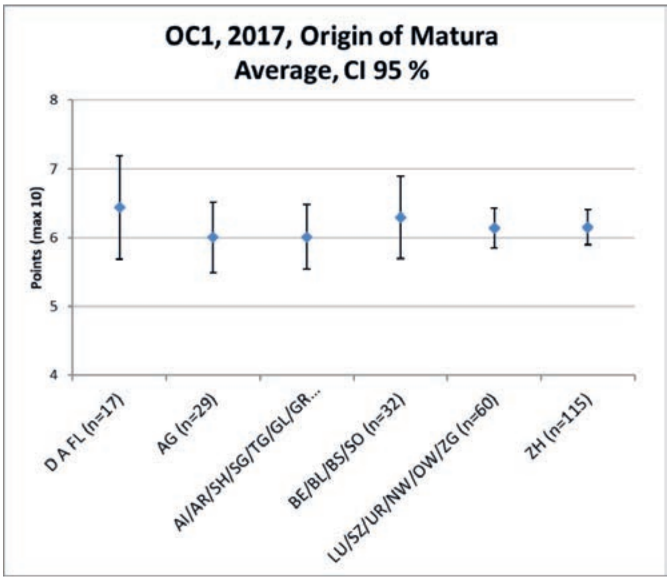

Fig. 3. Performance of OC1 students having obtained their *Matura* in different cantons or countries (*Standortbestimmung* 2017): D, A, FL (Germany, Austria, Liechtenstein), Swiss cantons AG (Aargau) and ZH (Zürich), and three regional groups of cantons. Average scores are normalized to a maximum of 10 and shown with 95% confidence intervals, n = number of participants.

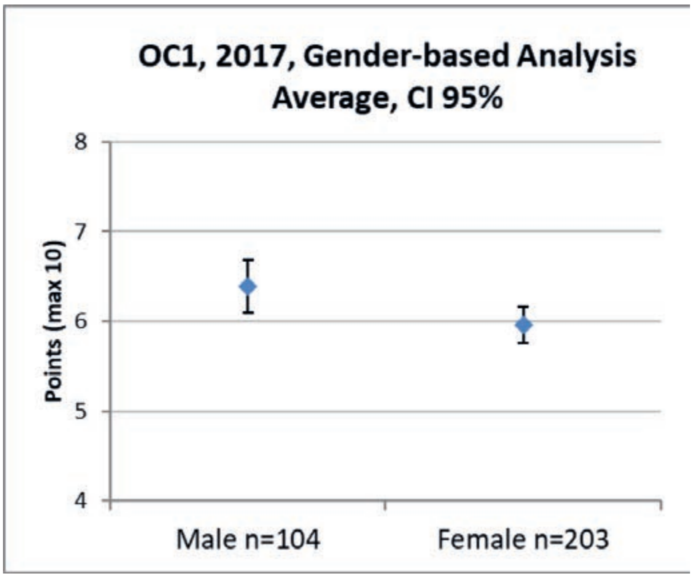

Fig. 4. Performance of OC1 students (*Standortbestimmung* 2017, n = 307) as a function of gender (male/female): Average scores are normalized to a maximum of 10 and shown with 95% confidence intervals, n = number of participants.

Table 3. Normalized average scores (1 ≙ 100%) for all questions, obtained by AC1 and OC1 students in the *Standortbestimmung* 2016. The color codes in the second column mark questions with low scores and/or high standard deviations. No. = question number; Pts = maximum achievable score (points); Mean = normalized average score; Stdev = standard deviation; n = count. Color code: dark green (high average score, small standard deviation) to red (low average score, high standard deviation).

		2016	**AC1**			**OC1**		
		Total (count)			**169**			**310**
		Topics	**Mean**	**Stdev**	**n**	**Mean**	**Stdev**	**n**
No.	Pts	**Atoms, PSE, Molecules, Compounds**						
9	1	Atom definition	0.740	0.256	169	0.695	0.267	310
10	1	Atom	0.704	0.362	167	0.573	0.415	307
11	2	Electrons, valence, molecular mass	0.896	0.153	169	0.840	0.215	310
12	2	Pure substances and mixtures	0.890	0.106	169	0.850	0.138	310
13	1	Radicals	0.845	0.223	169	0.725	0.267	309
14	1	Electronegativity	0.899	0.302	168	0.666	0.472	305
		Stoichiometry, Amount of Substance (mol)						
15	1	Reaction equations	0.947	0.153	168	0.897	0.215	306
16	1	Amount of substance, mol	0.805	0.267	169	0.705	0.280	309
17	1	Molecular mass	0.804	0.383	166	0.840	0.345	300
18	1	Calculate mass from amount of substance	0.826	0.369	164	0.805	0.381	287
19	2	Concentrations	0.933	0.218	164	0.856	0.307	298
20	2	Advanced stoichiometric question	0.563	0.476	128	0.317	0.464	191
		Molecules, salts, complexes						
21	2	Molecule geometry	0.870	0.219	166	0.835	0.230	308
22	2	Nomenclature	0.916	0.172	164	0.869	0.226	303
23	2	Formulae and names	0.768	0.229	164	0.625	0.321	301
24	2	Bonding in metal complexes	0.571	0.318	163	0.443	0.358	297
		Acids and bases, p_H, pK_a						
25	1	Definition of pH	0.873	0.332	166	0.777	0.416	309
26	1	Significance of pH-change	0.837	0.265	163	0.731	0.343	308
27	3	pH-Change upon addition of acid or base	0.739	0.254	162	0.639	0.261	294
28	2	Reaction of H_2SO_4 with $CaCO_3$	0.816	0.197	160	0.746	0.225	299
29	2	Interpretation of titration curves	0.563	0.329	150	0.403	0.274	271
		Redox chemistry						
30	1	Definition of redox reaction	0.939	0.172	165	0.852	0.262	308
31	1	Redox terminology	0.723	0.302	162	0.657	0.298	303
32	2	Redox terminology and reaction equation	0.544	0.327	153	0.374	0.271	271
33	2	Oxidation numbers	0.813	0.311	153	0.673	0.358	266
34	1	Terminology for galvanic cell	0.882	0.143	156	0.833	0.175	290
35	2	Processes in galvanic cell	0.703	0.345	146	0.502	0.322	282
		Thermodynamics, kinetics, equilibria						
36	2	Le Chatelier principle	0.652	0.357	148	0.465	0.312	282
37	2	Law of mass action (calculation)	0.497	0.500	147	0.355	0.479	276
38	2	Catalysts (cloze)	0.918	0.194	153	0.826	0.270	300
39	3	Thermodynamics (cloze)	0.783	0.207	153	0.725	0.225	295
40	2	Reaction-related changes in ΔH, ΔS, ΔG	0.594	0.252	127	0.558	0.213	249
		Organic chemistry						
41	1	Molecular formula and skeletal formula	0.876	0.330	153	0.811	0.392	291
42	1	Chirality	0.774	0.256	156	0.684	0.260	301
43	2	Identify stereogenic centers	0.841	0.191	142	0.690	0.266	264
44	1	Carotene - absorption of light	0.686	0.464	156	0.599	0.490	299
45	2	Polymers and corresponding monomers	0.866	0.227	149	0.806	0.266	284
		Total	**0.717**	**0.162**	**169**	**0.628**	**0.146**	**310**

OC1 and AC1 students, respectively. These scores would result in Swiss school grades of 4.3 (OC1) and 5.1 (AC1) (Swiss school grades range from 1 (lowest grade) to 6 (highest grade); in detail: grade 1 (0–4%) = *very weak*, grade 2 (≥20%) = *weak*, grade 3 (≥37%) = *insufficient*; grade 4 (≥55%) = *sufficient*; grade 5 (≥72.5%) = *good*, grade 6 *very good* (≥90%)). The observed difference in the average scores of the two groups of students may be explained to a large extent by the different backgrounds that the students acquired during their education at the high school level. Another aspect are different personal interests, which are reflected in the study program a student chooses. The students of the OC1 course are much more heterogeneous with regard to their interests, study goals and performance in chemistry, which is a secondary subject for them, whereas it is a main subject for the AC1 students. The heterogeneity of the OC1 students is also reflected by the fact that some of them drop chemistry after one year, whereas it becomes a core subject for others, if they choose an according sub-program in the course of their studies.

4.2 *Do we see a difference between the students who had chosen the high school focus or profile course biology and chemistry (Schwerpunktfach or Profil) or the elective chemistry course (Ergänzungsfach) as compared to those who took the general chemistry course (Grundlagenfach)?*

Using the OC1 data from the *Standortbestimmung* 2017, we looked at the performance of the students as a function of their scientific education at the high school level (Figs 3, 5, and 6). We compared students who took a general chemistry course (GL), a specific focus or profile biology and chemistry course (SF), and an elective chemistry course (EF). A significant difference was observed between the SF and GL groups. The SF group scored on average 15% higher and the results exhibited a smaller mean variation. The same trend was observed in previous years, *e.g.* in 2015, when the SF group of AC1 students outperformed the GL group by 13%.

In the *Standortbestimmung* 2017, no gender effect was observed with regard to the performance of OC1 students (Figs 4 and 6), neither for those who attended the general chemistry course (GL) nor for those with the specific focus on biology and chemistry (SF) at the high school level.

4.3 *Is there a difference in the performance of the AC1 students and the Biology-, Health Sciences- and Pharmaceutical Sciences sub-groups of OC1 students?*

Except for the 2016 biology students (OC1), a significant difference was observed in 2016 and 2017 between the average scores of the different sub-groups of OC1 students and those of the AC1 students (Fig. 7 and Table S4). The OC1 Biology students scored slightly better than those of Pharmaceutical Sciences, and both significantly better than those of Health Sciences. The average score of AC1 students exceeded that of Biology students (OC1) by *ca.* 7% in 2016 and even by 16% in 2017.

A comparison of the performances achieved by OC1 and AC1 students in the different sections (topics) of the 2016 and 2017 *Standortbestimmung* is presented in Fig. 8.

AC1 students generally performed better than OC1 students in all subject areas of the self-assessment. The most significant discrepancy is found for the topics *acids and bases* and *redox*

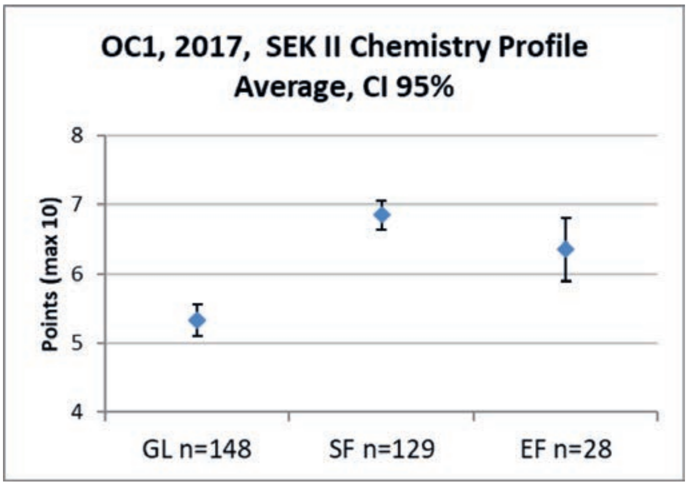

Fig. 5. Performance of OC1 students (*Standortbestimmung* 2017) as a function of their high school chemistry profile: GL = general chemistry course (*Grundlagenfach*), SF = specific focus or profile biology and chemistry (*Schwerpunktfach*), EF = elective chemistry course (*Ergänzungsfach*). Average scores are normalized to a maximum of 10 points; 95% confidence intervals are indicated; n = number of participants.

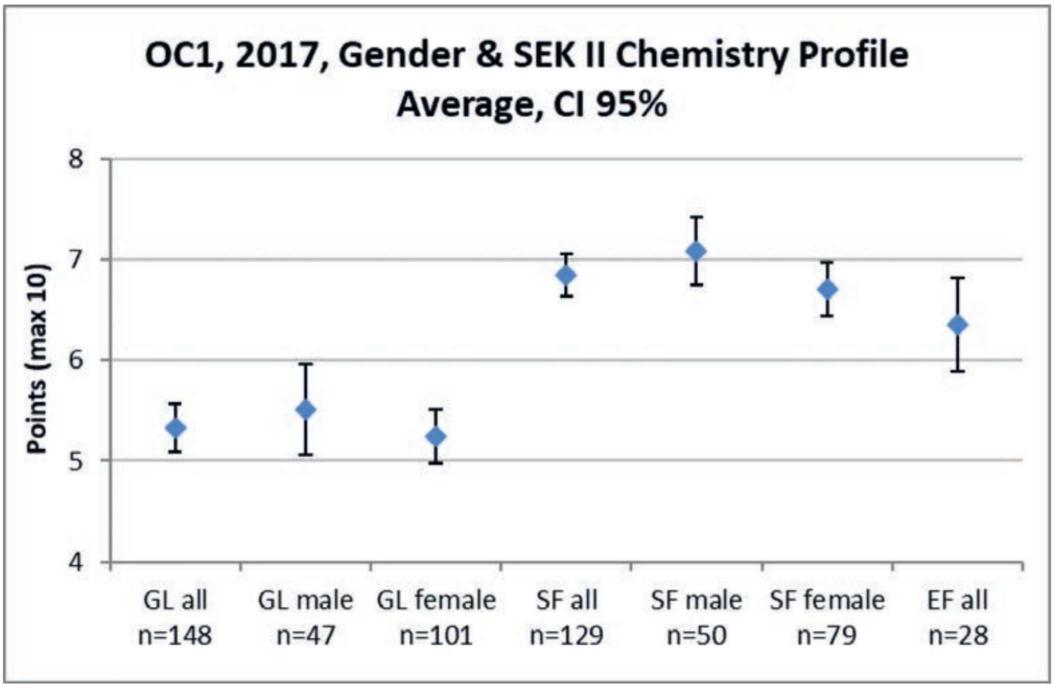

Fig. 6. Performance of OC1 students (*Standortbestimmung* 2017) as a function of gender (male/female) and their high school chemistry profile: GL = general chemistry course (*Grundlagenfach*), SF = specific focus or profile biology and chemistry (*Schwerpunktfach*), EF = elective chemistry course (*Ergänzungsfach*). Average scores are normalized to a maximum of 10 points; 95% confidence intervals are indicated; n = number of participants.

chemistry. The overall average score between OC1 and AC1 differ markedly, particularly in 2017. The lowest average scores were generally achieved in the *thermodynamics, kinetics and equilibria* section.

With a score of 55–73%, the average performance of the OC1 students was fair to good in the different sections of the test. On the other hand, the AC1 students, who have a stronger focus on chemistry, scored in the range between 68–84%, which can be rated as good to very good.

5. Conclusions

Generally speaking, the students who took AC1 or OC1 as a first-year chemistry course at ETH in 2016 and 2017 had a solid chemistry knowledge when they started their studies. Not only those who took a specific focus or profile on biology and chemistry course at the high school level, but also those with a general chemistry education did well in the *Standortbestimmung*. This gratifying result shows that the chemical education at high schools in Switzerland is capable of enabling students with a variety of backgrounds to start studies in the field of chemical sciences.

We found no indication for the performances being noticeably dependent on gender or region (Swiss cantons and German-speaking neighboring countries) in which the higher education entrance qualification (*Matura*) was obtained. Not unsurprisingly, the results of the *Standortbestimmung* were influenced by the secondary school profile of the students, but to a lesser extent than it may have been expected. We speculate that the role of personal interests and inclinations, which have not been the object of the current investigation, should not be underestimated

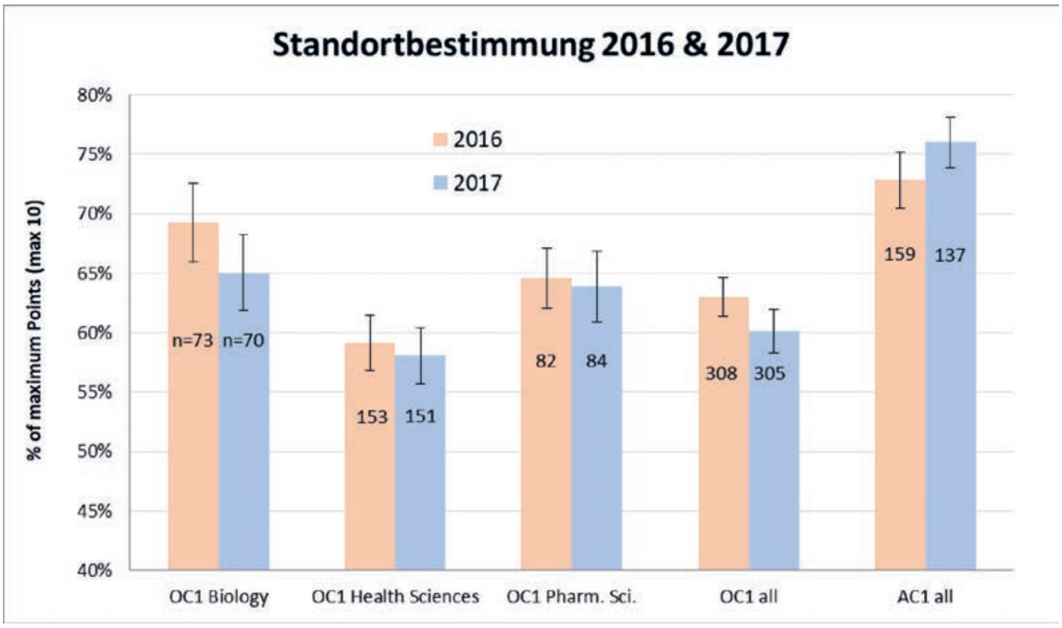

Fig. 7. Comparison of the *Standortbestimmung* performance of the different sub-groups of OC1 students and the AC1 students for 2016 and 2017. Averages are reflected by the column heights and 95% confidence intervals are indicated in addition to the number of participants (n). See also Tables S4 and 4.

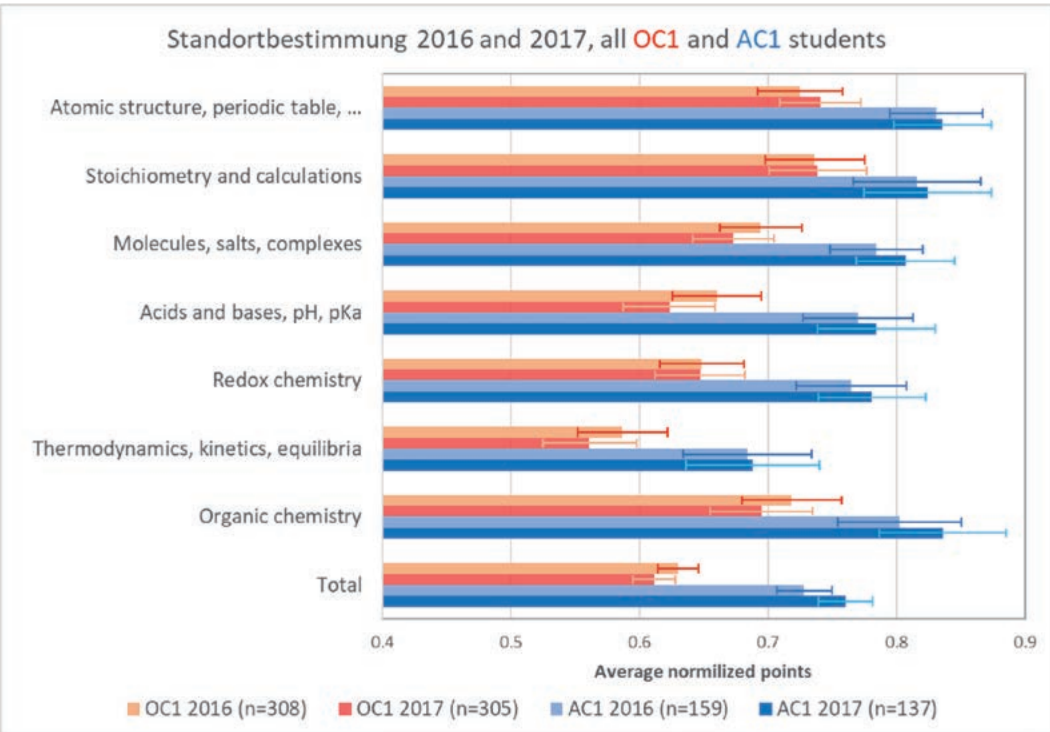

Fig. 8. Normalized average scores (1 ≙ 100%) obtained by OC1 and AC1 students in the *Standortbestimmung* and its various sections in 2016 and 2017. 95% confidence intervals are shown in the graph; n = number of participants.

as a factor having an impact on performance, not only at the outset, but also in the course of studies.

A major goal of the *Standortbestimmung* is to bring any gaps in chemistry knowledge to the attention of the students, thereby giving them a chance to fill these early on. Furthermore, the self-assessment data give the teaching assistants of the problem-solving sessions the opportunity to respond to specific needs of individual students and coach them more closely. On the other hand, the absence of major knowledge gaps will raise the students' level of self-confidence by showing that they can build upon a solid basic chemistry education from high school, thereby facilitating an efficient start into their academic studies. In the present survey, the discrepancy between the actual performance and the (lower) performance anticipated by the students shows that their self-confidence is certainly not overdeveloped. High school teachers are, therefore, encouraged to not only impart knowledge but also convey a certain level of self-confidence that will help students tackle new challenges.

Supplementary Information

Supplementary information is available on https://www.ingentaconnect.com/content/scs/chimia

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[6] One goal of the HSGym project is that *university lecturers should develop their knowledge of and their contacts with high schools (Gymnasien) in a targeted manner, while the high school teachers, as academically trained specialists, should regularly inform themselves about current developments, at least in their own discipline.*[5]
[6] Organische Chemie I (für Biol./Pharm.Wiss./HST), ETH course no. 529-1011-00.
[7] Allgemeine Chemie I (AC), ETH course no. 529-0011-02.

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