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Enhancing the transition? – effects of a tertiary bridging course in chemistry

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Preparatory or bridging courses are widespread and have a long tradition at universities. They are designed to increase students' academic success – in particular of students with low prior knowledge – and to reduce dropout rates. However, critics of these short and compact bridging courses complain that preparatory courses are not able to fill in content gaps sufficiently in a few weeks. Despite the high prevalence of university bridging courses, little is currently known about the sustainable learning efficacy of these courses. The aim of this study was to examine the short- and long-term effects of a traditional chemistry bridging course on students' success in the end of the semester examination of first-year chemistry students. For this purpose, students' learning outcomes were analyzed at the end of the two-week bridging course of students with different prior knowledge. Furthermore, it was investigated in an intervention-reference-group design whether students' exam results at the end of the first semester differ from participants of the bridging course and students who did not participate in the course. The results of the study reveal that students with low prior knowledge manage to close their content gaps in just a few weeks and to adjust differences in prior knowledge before starting their studies. At the end of the first semester, bridging course participants achieve significantly better exam results than their fellow students who did not enroll in the bridging course. However, mainly students with high prior knowledge seem to benefit from participating in the longer term. In the case of students with low prior knowledge, participation do not lead to better exam results compared to students without participation. Findings of the study can provide a basis for university teachers as well as university development experts to establish university bridging courses as well as to optimize existing offers.

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Introduction

Transition from high school to university is fraught with great challenges for many students and presents difficulties for many undergraduate students not least due to changes in learning and working methods and an increased workload. For the US, Kuh *et al.* (2008) show that the successful completion of the initial phase of a study course is of key importance for the success in university studies. Comparable results are reported by Heublein *et al.* (2017) for the German context. If students fail to complete or only insufficiently master the introductory phase of their studies, this can have far-reaching consequences for the course of studies and even lead to dropouts. The interview data of students who quit their studies show that freshmen who have difficulties finding their place at the university – especially at the beginning of their studies – do not fulfil performance requirements and postpone exams. They often feel overwhelmed by the professional level and have difficulties coping with the required workload (Heublein, 2014; Heublein *et al.*, 2017). The main reason for the high dropout rates in chemistry are performance problems. 37% of the students who quit their studies do not fulfil the requirements and a further 12% of the students fail the examinations (Heublein *et al.*, 2010). In this context, various studies indicate that a lack of understanding concepts in general chemistry (Busker *et al.*, 2010) and a lack of prior knowledge (Averbeck *et al.*, 2017) cause the subject-specific difficulties at the beginning of a course of study. These are also the main reasons identified by students who quit their studies because of poor performance (Heublein *et al.*, 2010). It is important to note that the sixteen federal states in Germany have relatively independent school policies. In the federal state of North Rhine-Westphalia, where this study was conducted, the students are able to choose basic or advanced courses after compulsory chemistry. In particular, German first-year undergraduate students who opt out of post-compulsory chemistry at upper secondary level show low prior knowledge. They differ significantly in their subject-specific knowledge from their fellow students, who have taken a basic or advanced post-compulsory chemistry course at upper secondary level. Although during the first semester they significantly improve their knowledge in general chemistry and achieve a comparatively high

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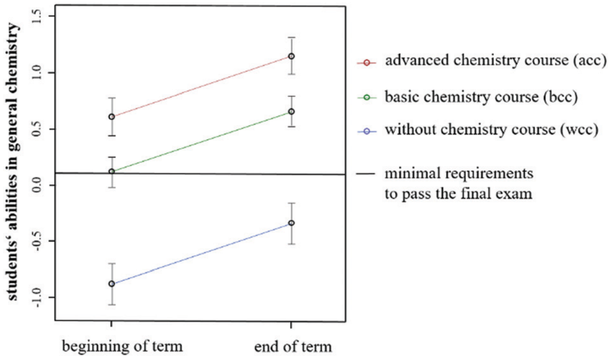

Fig. 1 Increase of content knowledge in general chemistry depending on students' choice of post-compulsory chemistry at upper secondary level (Averbeck, n.d., in preparation).

increase in knowledge, they do not manage to fill the gap between their knowledge and the knowledge of their fellow students (Averbeck *et al.*, 2017). According to the findings of Schwedler (2017), missing prior knowledge seems to make an important contribution to an excessive quantitative demand in the first semester. In this context, overtaxed students complain about the increased time which is necessary to fill in their content gaps. However, difficulties in understanding are only to blame to a lesser extent for poor performances by students with low prior knowledge, as Schwedler (2017) shows in her research. Averbeck *et al.* (2017) also reveal that knowledge in general chemistry, which was acquired during the first semester allows for only 15% of students, who opted out of chemistry at upper secondary level, to pass the final examination in general chemistry at the end of the term. Students who have completed a chemistry course at upper secondary level already have the necessary knowledge for a successful assessment at the beginning of their studies (*cf.* Fig. 1).

Against this background the question arises for many universities of how to properly deal with differences in prior knowledge of prospective chemistry students. As a tool for aligning the differences in prior knowledge, many universities offer preparatory or bridging courses, which start before the beginning of a semester and offer prospective students the opportunity to revise and reinforce their knowledge acquired at school, to fill in content gaps and strengthen their chemistry-specific skills. However, it is a widespread opinion that the development of competencies within these short-term and compact bridging courses is only possible to a limited extent and requires a longer period of time (Langemann, 2014). Despite the high prevalence of university preparatory courses, insights about the efficacy of these courses are limited so far. Currently, only a few studies exist that systematically examine short- and long-term effects of chemistry-specific bridging courses. The knowledge gained so far regarding the efficacy of preparatory courses for chemistry students can be traced back to studies that differ greatly in conception, duration, content and participants (Mitchell and de Jong, 1994; Chittleborough, 1998; Jones and Gellene, 2005; Botch *et al.*, 2007; Gadbury-Amyot *et al.*, 2009; Busker *et al.*, 2011; Schmid *et al.*, 2012; Dockter *et al.*, 2017). Although the results of these studies, which are discussed in more detail in the literature review section, have provided important insights into the effectiveness of subject-related bridging courses, a difficulty in the evaluation of such courses is also shown here, since a large number of variables can be considered, which makes it difficult to compare the findings of the studies among each other. The aim of this study is to develop a chemistry-specific bridging course, which improves the knowledge of participants with low prior knowledge in a way that they catch up with the high prior knowledge participants at the beginning of a study program. With this approach we try to enable students with low prior knowledge to successfully start their studies and to increase their academic achievement. Therefore, the short- and long-term effect of the bridging course on first-year students' knowledge and exam results will be investigated, especially of those with low prior knowledge. For this purpose, results of a study are presented in which the increase of knowledge and the exam results at the end of the first semester are analyzed and compared between bridging course participants with different prior knowledge. Findings of the study can provide a basis for university teachers as well as university development experts to establish university bridging courses as well as to optimize existing offers.

Literature review – bridging courses

A professional preparation of students in secondary education in terms of content knowledge is of main importance for a successful transition from school to university (Elliott *et al.*, 1996; Kuh *et al.*, 2011; Bottia *et al.*, 2015; Bottia *et al.*, 2018). Among other factors, a lack of academic preparation is closely linked to high dropout rates (Trusty, 2002; Maltese and Tai, 2011; Rozek *et al.*, 2017). In order to counteract the problem of inadequate professional preparation, many universities established preparatory or bridging courses (Warburton *et al.*, 2001; Pascarella *et al.*, 2004; Kuh *et al.*, 2006). They are offered as non-compulsory, short and intensive bridging courses before the beginning of the semester or as voluntary one-semester long courses. In the light of increasing heterogeneity in undergraduate students' knowledge, bridging courses provide a cost-effective way to facilitate the transition from school to university by closing content gaps in students' prior knowledge and supporting the learning of new chemistry specific content knowledge. However, little is known so far about the effectiveness of these offers. For the widespread mathematics bridging courses, results of several studies indicate that participants of the course withdraw from final exams less often (Poladian and Nicholas, 2013) and achieve better exam results than those students who did not enroll in the bridging course (Poladian and Nicholas, 2013; Grabowski and Kaspar, 2014; Greefrath and Hoever, 2016). However, only a handful of studies exist for chemistry-specific bridging courses, among which the majority deal especially with the development and evaluation of one-semester long programs (Mitchell and de Jong, 1994; Chittleborough, 1998; Jones and Gellene, 2005; Gadbury-Amyot *et al.*, 2009). So far, little attention has been payed to the short and compact chemistry bridging courses (Botch *et al.*, 2007; Busker *et al.*, 2011; Schmid *et al.*, 2012). Given the fact that chemistry-specific prior knowledge is one of the strongest predictors of study success – measured as the final grade at the end of the first semester (Averbeck *et al.*, 2017) – these short but intensive bridging courses seem to be an appropriate offer to balance differences in prior knowledge even before the beginning of the semester and to help students with low prior knowledge to successfully finish their studies and to avoid dropouts. If it is not possible to close the content gaps even before the beginning of the study or directly in the study entry phase, this favors a dropout (Heublein *et al.*, 2017). Surprisingly, there are only a few studies that have dealt with the short- and long-term impact of non-compulsory, temporary chemistry bridging courses on the final exam results at the end of the first semester in the last 20 years.

In a study of Botch *et al.* (2007) the learning efficacy of an online preparatory course in the field of chemistry was investigated, in which students were provided with information materials and exercises for self-study before the beginning of the semester. Participants could choose for themselves on which topics they wanted to work and how much time they wanted to spend in the course. In addition, they had the opportunity to receive detailed feedback on exercises and to talk to interactive tutors. The results of the study reveal that students who had enrolled in the online preparatory course had achieved on average significantly better grades at the end of the first semester than their fellow students who had not participated in the course before the beginning of the semester. However, it is still unclear whether the better grades of the participants can solely be attributed to the participation in the bridging course or if it is also connected to higher cognitive abilities or to differences in prior chemistry-specific content knowledge. On the one hand participants of the bridging course were academically stronger than the non-users, demonstrating higher mathematical and verbal scores, on the other hand, students' content knowledge in the field of general chemistry was not measured. Comparable limitations are also shown in a study of Schmid *et al.* (2012), in which the efficacy of a one-week chemistry preparatory course for the final exam at the end of the first semester was examined. The preparatory course was traditionally structured into lectures and tutorials and did not differentiate between participants with low or high prior content knowledge. Although the results of the study show that participation in the preparatory course improved students' performance overall and participants achieved better results than non-users with low prior knowledge, differences do not reach statistical significance. To what extent the better exam results of bridging course users are influenced by the course participation itself or by higher chemistry-specific prior knowledge of the participants, cannot be answered with absolute certainty by this study, because students' prior content knowledge in the field of general chemistry was not measured. Summing up, it can be stated that the non-compulsory and intensive preparatory courses, which start before the beginning of the first semester, seem to be an effective offer to increase students' knowledge and fortunately participants feel better prepared for their studies than their fellow students who did not enroll in the preparatory course (Teo *et al.*, 2011; Schmid *et al.*, 2012; McLaughlin *et al.*, 2017). Whether these time-limited bridging courses have a long-term effect on students' final exam results and are able to fulfil the aim of aligning students' content knowledge, which is generally linked to participation in a bridging course, is an open question for further research.

Research aim and questions

The aim of the study is to investigate the short- and long-term effect of a chemistry-specific bridging course on the increase in chemistry-specific content knowledge and the success in the final exam of German first-year students, especially of those with low prior knowledge. In this context, one aim is to align the chemistry-specific content knowledge at the end of the bridging course (post ck) of the participants without a post-compulsory chemistry course in upper secondary level (wcc) with the chemistry-specific content knowledge before the bridging course (pre ck) of the participants who have chosen an advanced post-compulsory chemistry course at upper secondary school (acc). The underlying research question is:

RQ1 To what extent can differences be found at the end of the bridging course between the acquired content knowledge (post ck) of bridging course participants who drop chemistry at upper secondary school (wcc) and the content knowledge before the bridging course (pre ck) of participants who have chosen an advanced chemistry course at upper secondary school (acc)? (short-term effect).

In addition, we aim to investigate whether students with low prior knowledge benefit from the bridging course at the end of the first semester in terms of their final exam results. The underlying research question is:

RQ2 To what extent can differences be found between the final exam results in general chemistry (at the end of the first semester) of bridging course participants and non-participants, who did neither take a basic nor an advanced chemistry course at upper secondary school (wcc)? (long-term effect).

Conception of the bridging course

Against this background, we designed a joint, two-week, non-compulsory chemistry bridging course for all courses of study with an affinity to chemistry (with the exception of engineering sciences). The bridging course is offered annually before the beginning of the first semester and consists of a daily lecture and a tutorial. Topics of the bridging course are based on contents of the lecture in general chemistry which is offered for all BSc Chemistry and BSc Water Science students in the first semester. Topics covered by the bridging course include atomic structure, ionic and covalent bonding, stoichiometry, kinetics, thermodynamics, redox and acid–base chemistry, which are taught at upper secondary school and of special importance for the lecture in general chemistry. Moreover, some of the contents of the first semester like the orbital model are also provided. Since the lecture format with a 90 minute lecture is unusual and tedious for the majority of the participants, quiz questions have been integrated with the web-based voting system Pingo for

Table 1 Participants' intended study programs

Medicine	Biology	Chemistry	Chemistry teacher program	Biology teacher program	Physics	Water Science	Energy Science	Not stated/other	Total
N = 88	N = 45	N = 38	N = 23	N = 21	N = 18	N = 15	N = 14	N = 25	N = 287

cognitive activation of the participants. This tool facilitates interactions between the teacher and participants and initializes discussions by interrogating knowledge anonymously. The tutorial sessions give students the opportunity to apply the principles covered in the preceding lecture with learning materials and the help of a tutor. Therefore, the tutorials are conducted in groups no larger than 25 students.

Research design and instruments

As part of the preparatory course program at the University of Duisburg-Essen, the two-week chemistry bridging course was offered immediately before the beginning of the winter semester 2017/2018. In order to meet the high demand for places in the bridging course, the course was offered twice in identical form in first and last two weeks of September 2017. To answer the first research question, the short-term effect of the bridging course on students' learning success was investigated in a pre-post design by comparing the acquired content knowledge (post ck) of students with low prior knowledge (wcc) with the content knowledge (pre ck) of students with high prior knowledge (acc). Students' chemistry-specific content knowledge was captured with a standardized content knowledge test (Freyer, 2013) on the first and last day of the bridging course. The test consists of 37 multiple-choice single-select items and captures knowledge in the field of general chemistry. An additional questionnaire was used on the first day of the bridging course to determine students educational background like demographic data, grade point average and data of an enrollment in a university program as well as chosen subjects in natural sciences at upper secondary school. The information whether a chemistry course was chosen in upper secondary level or not allows us to draw conclusions from their chemistry-specific prior content knowledge, since the course level of the chemistry course taken represents one of the strongest predictors of prior knowledge in the field of general chemistry (Averbeck *et al.*, 2017). To answer the second research question, the long-term effect of the bridging course on students' exam results is examined in an intervention-reference-group design by comparing bridging course participants with low prior knowledge (wcc) (intervention group) with non-users with comparable low prior knowledge (wcc) (reference group). In this context, students' final exam results in the field of general chemistry are measured as scores per exercise and as final grade from all BSc Chemistry and BSc Water Science students at the end of the first semester. For all students who did not enroll in the bridging course, prior content knowledge and grade point average were subsequently captured with a questionnaire in a course at the beginning of the first semester. Furthermore, students were asked if they are satisfied with the course on the last day of the bridging course with an additional questionnaire.

Sample

To answer the first research question, all participants of the bridging course who participated in one of the two identical courses in 2017 will be included in the analyses. In total, data are available for N = 287 participants (63% female, average age 19 years), 18.5% of whom say they want to study BSc Chemistry or BSc Water Science. The BSc Water Science program is a program with large overlaps with the BSc Chemistry program. The other participants actually intend to study other programs in which they are less confronted with chemical contents (*cf.* Table 1).

To answer the second research question, only those participants are considered who are enrolled in the BSc Chemistry or BSc Water Science course, since they attend the same general chemistry course in the first semester and also write the same exam at the end. This subsample of the bridging course participants thus forms the intervention group of the study, which attended both the bridging course and the general chemistry course in the first semester. In contrast, those students who did not attend the bridging course but attended the general chemistry course in the first semester and took the written exam are used as the reference group (*cf.* Table 2). Since too little data on the choice of chemistry course is available from the reference group of the student cohort in 2017, data from BSc Chemistry and BSc Water Science students of the following year are additionally used to answer the second research question. This cohort of students attended the same chemistry preliminary course in 2018 or took part in the same course in the first semester with the same final exam at the end. The daily lecture of the bridging courses in 2017 and 2018 was given by the same instructors, so that effects given by the instructor can be mostly excluded. A reference of the GPAs between the bridging course participants in 2017 and 2018 shows that there are no significant differences between the two cohorts ($t(96) = -0.327$, $p = 0.744$, $d = 0.07$). It can therefore be assumed that the student groups are comparable in terms of cognitive performance in the subject.

Results

Short-term effect of the bridging course

On the first day of the bridging course in 2017 260 participants completed the content knowledge test. In course of the two

Table 2 Overview of the intervention and reference group

	Participated in the two-week bridging course	Participated in the general chemistry course within the first semester
Experimental group (N = 76)	+	+
Reference group (N = 73)	–	+

Table 3 Distribution of the participants (student cohort 2017, intervention group) with respect to their chemistry course in upper secondary

Number of students without a chemistry course (wcc)	Number of students with a basic chemistry course (bcc)	Number of students with an advanced chemistry course (acc)
N = 137	N = 98	N = 30

N = 22 participants have not stated their chemistry course at upper secondary level.

weeks 107 prospective students dropped out resulting in 153 participants who completed the post test on the last day of the bridging course. Accordingly, 132 complete data sets were available and could be used for further analyses. Since there was no possibility to find out more about the reasons why these students did not attend all sessions of the course, we can only make assumptions at this point. One possible reason could be that the students decided during the course that the contents were too easy or too difficult for them. Another reason could be that the format of the course did not match their expectations.

With a Cronbach's alpha of $\alpha = 0.74$ both the pre and post content knowledge test showed sufficient internal consistency at both measurement time points. Half of the final sample (51.7%) did not take a chemistry course in upper secondary (*cf.* Table 3) which is the main target audience for the bridging course.

In a first step the results of an univariate analysis of variance (ANOVA) reveal significant differences regarding the chemistry related prior knowledge of the participants depending on their chemistry course in upper secondary ($F(2,256) = 51.006$, $p < 0.001$, $\eta^2 = 0.285$) (*cf.* Fig. 2). As expected participants who did not take a chemistry course in upper secondary (wcc) showed the lowest chemistry related prior knowledge ($M = 12.50$, SD = 4.41). *Post hoc* comparisons using the LSD test indicate that their prior knowledge is significantly ($p \leq 0.001$) lower compared to participants who took a basic chemistry course (bcc) ($M = 15.72$, SD = 4.20) and an advanced chemistry course (acc) respectively ($M = 21.28$, SD = 4.49).

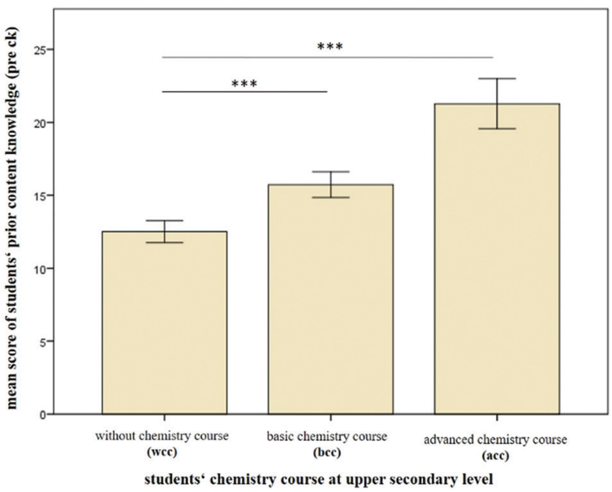

Fig. 2 Participants' chemistry related prior knowledge depending on their chemistry course in upper secondary. (Error bar: 95% confidence interval, ***: $p \leq 0.001$).

Taking a closer look at the pre-post data of the content knowledge test by applying a repeated measures ANOVA it can be noted that all students regardless of their course level in upper secondary show significant learning gains with a large effect size ($F(1,131) = 213.96$, $p \leq 0.001$, $\eta^2 = 0.620$). However, the learning gains of the three course groups differ significantly ($F(2,128) = 23.186$, $p \leq 0.001$, $\eta^2 = 0.266$) (*cf.* Table 4).

To answer the first research question we compared the performance of the students with weak chemistry background (wcc) at the end of the bridging course with the initial performance of the students with a strong background in chemistry (acc). A conducted independent t-test shows no statistically significant differences between the mean post score of the students with weak chemistry background (wcc) and the mean pre score of the students with strong chemistry background (acc). The results suggest that focusing content knowledge, the prospective students who did not take a chemistry course in upper secondary (wcc) reduce the difference observed in the pre-measure by attending the chemistry bridging course, at least in the short term ($t(95) = -1.69$, $p = 0.095$, $d = 0.37$) (*cf.* Fig. 3). In the same way participants who took a basic chemistry course in upper secondary (bcc) were able to extend their knowledge base in general chemistry in a way that no statistically significant differences between their mean post score and the mean pre score of the students with a strong chemistry background (acc) could be found ($t(79) = 0.14$, $p = 0.887$, $d = 0.03$) (*cf.* Fig. 3).

Long-term effect of the bridging course

In order to gain first insights in the long-term effects of the bridging course we compared the academic achievement of the students who did participate in the chemistry bridging course prior to their regular study program (experimental group) with the academic achievement of students who did not participate in the bridging course (reference group). An appropriate measure for chemistry related academic achievement is the students' performance in the general chemistry exam at the end of the first semester. Similar to the results of Botch *et al.* (2007) and Schmid *et al.* (2012) the students who participated in the bridging course ($N = 34$, $M = 51.76$, SD = 20.16) obtained better results in the exam than students wo did not participate ($N = 73$, $M = 43.30$, SD = 20.34) ($F(1,105) = 4.038$, $p = 0.047$, $\eta^2 = 0.037$) (*cf.* Fig. 4).

Table 4 Means and standard deviations for the pre and post content knowledge test depending on the participants' course level in upper secondary

	Pre content knowledge (pre ck)		Post content knowledge (post ck)	
No chemistry course (wcc) (N = 63)	M = 12.70	SD = 4.68	M = 19.64	SD = 4.72
Basic chemistry course (bcc) (N = 50)	M = 16.06	SD = 4.98	M = 21.54	SD = 0.54
Advanced chemistry course (acc) (N = 18)	M = 21.67	SD = 4.41	M = 25.67	SD = 3.24

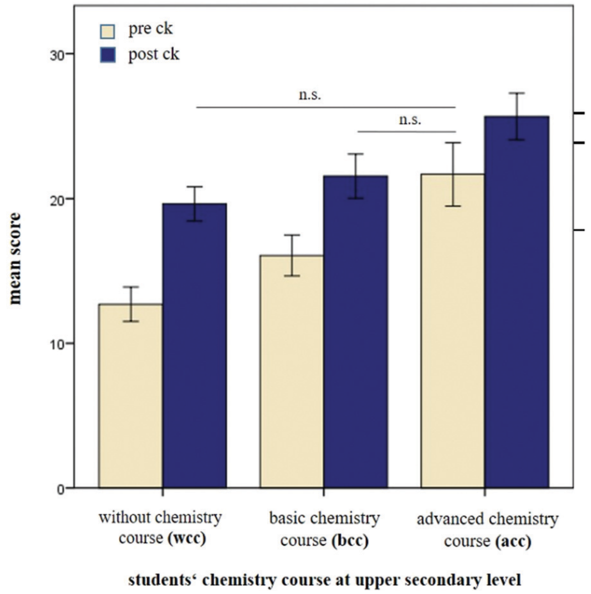

Fig. 3 Pre and post content knowledge scores depending on the participants' course level in upper secondary. (Error bar: 95% confidence interval, n.s.: not significant).

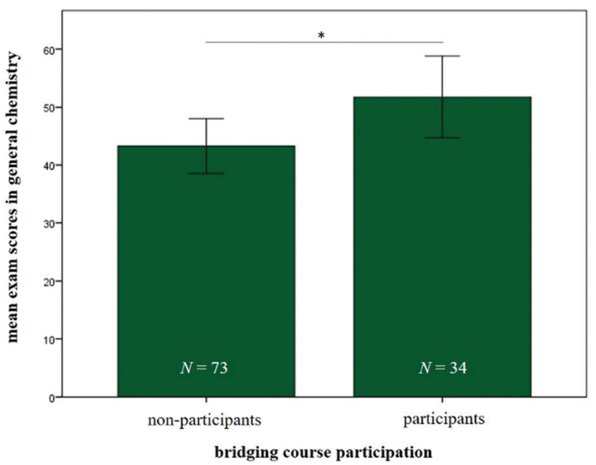

Fig. 4 Mean exam scores in general chemistry for students who did and did not attend the chemistry bridging course before their regular program. (Error bar: 95% confidence interval; *: $p \leq 0.05$).

When the GPAs of all students are considered as a covariate the test score differences remain significant. No significant differences regarding the mean GPA of the experimental group (M = 2.4, SD = 0.64) and the control group could be found (M = 2.5, SD = 0.72) ($t(82) = 0.656$, $p = 0.513$, $d = 0.14$). Taking the participants course level in upper secondary in consideration it strikes that high exam scores are achieved by students who took an advanced chemistry course (acc) and therefore had the highest prior knowledge (M = 61.81, SD = 17.50) (*cf.* Fig. 5). Students who attended the bridging course and did not take a chemistry course in upper secondary (wcc) (M = 44.19, SD = 16.75) score significantly lower than students who participated in the course and took an advanced chemistry course (acc)

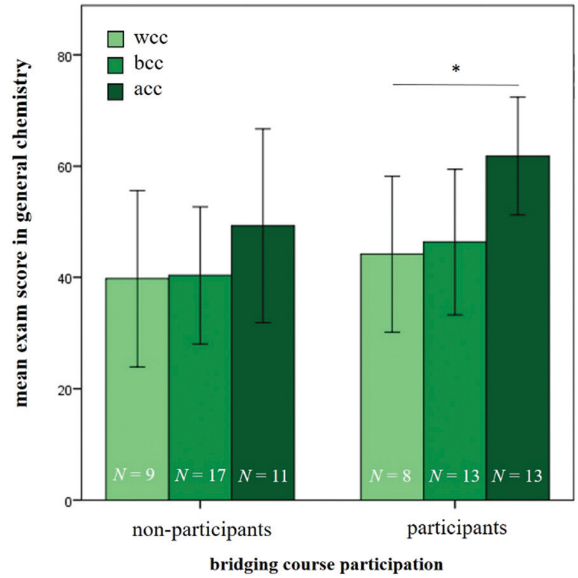

Fig. 5 General chemistry exam scores for students who did and did not participate in the bridging course dependent on their course level in upper secondary. (Error bar: 95% confidence interval, *: $p \leq 0.05$).

($t(19) = -2.276$, $p = 0.035$, $d = 1.03$). However, it should be noted that the difference is no longer significant after Bonferroni correction. Interestingly and in light of the second research question the results show that there are no relevant exam score differences between students with a weak chemistry background (wcc) who did and did not participate in the bridging course (M = 39.78, SD = 20.60) respectively. It can be concluded that students with a strong chemistry background from upper secondary (acc) benefit most from participating in the chemistry bridging course in the long term. While those students, the bridging course is meant to support, are able to catch up regarding the level of content knowledge in general chemistry in the short term, they cannot use this knowledge in a way that leads to better performances in the general chemistry exam at the end of the first semester. Although the results raise new questions regarding the sustainability of the bridging courses' effects, they have to be carefully interpreted due to the relatively small sample sizes. There is a need for further studies which systematically investigate the short- and long-term effects of domain specific bridging courses on students' academic achievement.

For further evaluation of the bridging course the participants had the opportunity to evaluate the program from various points of view at the end of each course. Overall the participants' feedback was quite positive. For instance, this is shown by the fact that 87.3% (N = 141) of the participants would recommend the preliminary course to others. This may also be due to the fact that the perceived difficulty of the preliminary course was *"exactly right"* for 44.7% of the participants and more than half of the participants (53.6%) felt that their own learning success was *"high"* and *"very high"* respectively. The participants from 2018 also come to an almost identical conclusion. Suggestions for improvement are also made with regard to how participants deal with their prior knowledge. In this context, the participants of the bridging course would like to see a stronger differentiation between students with a high or low level of previous knowledge in the design of the program.

It should be noted in a limiting way that the evaluation took place at the end of the bridging course and the students who had already dropped out of the course did not participate. Therefore, the above mentioned percentages are relative and should not be overestimated. It would also be interesting to obtain the assessments of those students who have dropped out of the course in the meantime. For organizational and privacy reasons, this was unfortunately not possible within the scope of this study.

Discussion and conclusion

The persistent high dropout rates in higher education chemistry programs of 42% in Germany (Heublein *et al.*, 2017) and their causes show an urgent need for action. Universities and tertiary educational institutions have to deal with deficient domain specific prior knowledge which is one of the main reasons for difficulties in the study entry phase for many students (Heublein *et al.*, 2010; Averbeck *et al.*, 2017). Especially when a student starts his or her program with low prior knowledge in general chemistry the learning opportunities of the first semesters oftentimes do not suffice to pass the general chemistry exam at the end of the semester despite the comparable high learning gains (Averbeck *et al.*, 2017). Results of a study from Schwedler (2017) indicate that students with low prior knowledge can be overwhelmed by the amount of time they have to invest to catch up. Following this argumentation, it can be assumed that low prior knowledge students need more than one semester to adequately close their prior knowledge gaps.

In this context higher education bridging courses are a promising instrument which can help to adjust existing differences in subject specific prior knowledge of prospective students and thus support them in their study entry phase. Surprisingly we still do not know much about the short and long-term effects of optional university bridging courses on students' domain specific academic achievement. A limitation of most studies in this context is that most studies do not control for the courses' pedagogy, their duration and the concrete contents which are covered. Further they often lack appropriate control variables like domain specific prior knowledge, a measure of cognitive abilities and their baseline effect on academic achievement in the study entry phase thus effects caused by bridging courses may become blurred (Botch *et al.*, 2007; Schmid *et al.*, 2012).

Benefits

The aim of this study was therefore to examine the short- and long-term effect of a chemistry bridging course on the learning growth and the success of first-semester students, especially those with low prior knowledge. The results of the study confirm that pre-study and bridging courses can be a valuable university support offer with which students can close gaps in their subject specific content knowledge and equalize differences in previous knowledge even before they begin their studies. For example, the participants of the chemistry bridging course with low prior knowledge catch up within only two weeks and reduce differences in prior knowledge compared to fellow students who took an advanced chemistry course in upper secondary. At the end of the bridging course they reach a level of knowledge that corresponds to that of a student who would start his studies with a high level of prior knowledge but without attending the chemistry bridging course. The results of the study confirm that attending the chemistry bridging course is also rewarding for students with a high level of prior knowledge, and that these students also have significant learning gains at the end of the two weeks. In the light of these results and the fact that bridging courses are usually non-compulsory, further research should examine what might stop students from participation and what might incentivize them to attend. Moreover, it should be analyzed if a diagnostic could help students – especially with low prior knowledge – to estimate their knowledge more precisely.

If one considers the long-term effect of the chemistry bridging course on the exam success of first-semester students, the results show that at the end of the semester the bridging course students achieve significantly better exam results on average than their fellow students who did not attend the bridging course.

Missed gains and limitations

However, taking a closer look at the exam performance of students with low previous knowledge with and without participation in the bridging course, there are no significant differences in favor of those taking the course. This means, on the one hand, that the actual target group of the bridging course does not seem to be able to make sufficient use of the content knowledge gained in the course with regard to the written exam at the end of the first semester to their advantage. On the other hand, the better exam performance of the bridging course students can be merely traced back to those students with a high level of prior knowledge.

The question that therefore arises is for what reason do students with low domain specific prior knowledge fall short of expectations with their written examinations despite taking part in the bridging course and the learning gains achieved there? First, the results should certainly be interpreted with caution, as the sample size for group comparisons is relatively small and students from two cohorts are also compared. In addition, the intervention group is a positive selection of first-semester students, who are probably more motivated to study and willing to make an effort than students who did not participate in the bridging course. Nevertheless, it can be assumed that it will not be possible to build up such a deep and comprehensive understanding of the concepts within the two weeks that students will be able to build on it in the course of the first semester and adequately embed new subject content. It is also possible that the mathematical skills taught in the chemistry bridging course are not sufficient for many students to meet the requirements in the first semester. This is because the required level in abstract mathematics in particular leads to problems for many first-semester students in chemistry studies (Parchmann *et al.*, 2011; Schwedler, 2017).

According to Kimpel (2018), exam tasks that require students to perform specific arithmetic operations in the chemical context represent a particular challenge. In addition, individual personality traits, such as the willingness and conscientiousness of the students to make an effort, as well as affective factors, such as study motivation, which is an important predictor of academic success in chemistry (Averbeck *et al.*, 2017), must certainly also be taken into account when interpreting the results. Little is known about the students' learning time invested in the first semester and their motivation to study, since it was not possible to check how regularly they attended lectures and exercises for which they were not required to attend. Finally, it must also be critically questioned to what extent the chemistry bridging course, which only lasted two weeks, can at all be able to completely compensate for differences in previous knowledge that have grown over several years and to develop a comprehensive understanding of concepts that corresponds to that of students who were taught in an advanced course for two years. It needs to be noted that students with a high level of prior knowledge are likely to be able to better integrate the contents of the course in order to develop and deepen existing concepts. Although the results show that students with low prior knowledge also benefit from the course, it would be interesting to investigate the quality of the learning gains of both groups more closely in the context of future research. In view of the poor exam results of students with low prior knowledge and the results of this study, it can therefore be concluded that additional assistance may be necessary in the course of the first semester, which draw on the content knowledge built up in the bridging course. On the other hand, a higher degree of differentiation within the bridging courses appears promising, which takes heterogeneity of the learning group into account. This is at least suggested by the findings from Dockter *et al.* (2017) who showed that an online, adaptive-responsive preparatory chemistry course provided enhanced academic preparedness when compared to a traditional, classroom-based preparatory chemistry course. Furthermore, participants of the bridging course have already made corresponding suggestions in this direction.

Statement of ethics

The research adhered to ethical standards and guidelines as the nature of study demanded. Consent was collected of the participants and the statistical analysis was performed using non-identifiable data.

Conflicts of interest

The authors have no conflicts of interest to declare in relation to this work.

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References

Averbeck D., (n.d.), Zum Studienerfolg in der Studieneingangsphase des Chemiestudiums – der Einfluss kognitiver und affektiv-motivationaler Variablen [Study success in the study entry phase of chemistry studies – the influence of cognitive and affective-motivational variables], (Unpublished doctoral dissertation), Essen: Universität Duisburg-Essen, in preparation.

Averbeck D., Fleischer J., Sumfleth E., Leutner D. and Brand M., (2017), Analyse chemischen Fachwissens und dessen Einfluss auf Studienerfolg [Analysis of students‘ chemistry-specific content knowledge and its impact on study success], in Maurer C. (ed.), *Implementation fachdidaktischer Innovation im Spiegel von Forschung und Praxis, Gesellschaft für Didaktik der Chemie und Physik, Jahrestagung in Zürich 2016*, Universität Regensburg, pp. 83–87.

Botch B., Day R., Vining W., Stewart B., Hart D., Rath K. and Peterfreund A., (2007), Effects on student achievement in general chemistry following participation in an online preparatory course. Chemprep, a voluntary, self-paced, online introduction to chemistry, *J. Chem. Educ.*, **84**(3), 547–553.

Bottia M. C., Stearns E., Mickelson R. A., Moller S. and Parker A. D., (2015), The Relationships among High School STEM Learning Experiences and Students' Intent to Declare and Declaration of a STEM Major in College, *Teach. Coll. Rec.*, **117**(3), n3.

Bottia M. C., Stearns E., Mickelson R. A. and Moller S., (2018), Boosting the numbers of STEM majors? The role of high schools with a STEM program, *Sci. Educ.*, **102**(1), 85–107, DOI: 10.1002/sce.21318.

Busker M., Parchmann I. and Wickleder M., (2010), Eingangsvoraussetzungen von Studienanfängern im Fach Chemie.: Welches Vorwissen und welche Interessen zeigen Studierende? [Entrance requirements for first-year students in chemistry: What prior knowledge and interests do students have?], *Chemkon*, **7**(4), 163–168, DOI: 10.1002/ckon.201010134.

Busker M., Klostermann M., Herzog S., Huber A. and Parchmann I., (2011), Nicht nur Schulwissen auffrischen: Vorkurse in Chemie [Not just refreshing school knowledge: Pre-courses in Chemistry], *Nachr. Chem.*, **59**, 684–687.

Chittleborough G., (1998), *An evaluation of student learning during a tertiary bridging course in chemistry*, Doctoral dissertation, Curtin University of Technology.

Dockter D., Uvarov C., Guzman-Alvarez A. and Molinaro M., (2017), Improving preparation and persistence in undergraduate STEM: why an online summer preparatory chemistry course makes sense, *Online Approaches to Chemical Education*, American Chemical Society, pp. 7–33, DOI: 10.1021/bk-2017-1261.ch002.

Elliott R., Strenta A. C., Adair R., Matier M. and Scott J., (1996), The role of ethnicity in choosing and leaving science in highly selective institutions, *Res. Higher Educ.*, **37**(6), 681–709.

Freyer K., (2013), *Zum Einfluss von Studieneingangsvoraussetzungen auf den Studienerfolg Erstsemesterstudierender im Fach Chemie [The Influence of Entrance Requirements on the Success of First Semester Chemistry Students]*, Berlin: Logos.

Gadbury-Amyot C. C., Overmann P. R. and Crain G., (2009), The Development and Implementation of an Online Applied Biochemistry Bridge Course for a Dental Hygiene Curriculum, *J. Dent. Educ.*, **73**(1), 83–94.

Grabowski B. and Kaspar M., (2014), MathCoach: ein intelligenter programmierbarer Mathematik-Tutor und sein Einsatz in Mathematik-Brückenkursen [MathCoach: an intelligent programmable mathematics tutor and its use in mathematics bridge courses], in Bausch I. *et al.* (ed.), *Mathematische Vor- und Brückenkurse. Konzepte, Probleme und Perspektiven*, Wiesbaden: Springer Spektrum, pp. 277–294, DOI: 10.1007/978-3-658-03065-0.

Greefrath G. and Hoever G., (2016), Was bewirken Mathematik-Vorkurse? Eine Untersuchung zum Studienerfolg nach Vorkursteilnahme an der FH Aachen [What are the effects of mathematics pre-courses? A study on the success of studies after attending a pre-course at the FH Aachen], in Hoppenbrock A. *et al.* (ed.), *Lehren und Lernen von Mathematik in der Studieneingangsphase*, Wiesbaden: Springer Fachmedien, pp. 517–530, DOI: 10.1007/978-3-658-10261-6_33.

Heublein U., (2014), Student Drop-out from German Higher Education Institutions, *Eur. J. Educ.*, **49**(4), 497–513, DOI: 10.1111/ejed.12097.

Heublein U., Hutzsch C., Schreiber J., Sommer D. and Besuch G., (2010), *Ursachen des Studienabbruchs in Bachelor- und in herkömmlichen Studiengängen [Causes of the discontinuation of studies in Bachelor's and conventional courses of study]*, HIS-Projektbericht, HIS: Hannover.

Heublein U., Ebert J., Hutzsch C., Isleib S., König R., Richter J. and Woisch A., (2017), Zwischen Studienerwartungen und Studienwirklichkeit: Ursachen des Studienabbruchs, beruflicher Verbleib der Studienabbrecherinnen und Studienabbrecher und Entwicklung der Studienabbruchquote an deutschen Hochschulen [Between Study Expectations and Study Reality: Causes of Termination of Studies, Occupational Reasons for Termination of Studies and Development of the Rate of Termination of Studies at German Universities], *Forum Hochschule*, p. 1.

Jones K. B. and Gellene G. I., (2005), Understanding Attrition in an Introductory Chemistry Sequence Following Successful Completion of a Remedial Course, *J. Chem. Educ.*, **82**(8), 1241–1245.

Kimpel L., (2018), *Aufgaben in der Allgemeinen Chemie: Zum Zusammenspiel von chemischem Verständnis und Rechenfähigkeit [Tasks in General Chemistry: The Interaction of Chemical Understanding and Computational Ability]*, Berlin: Logos.

Kuh G. D., Kinzie J. L., Buckley J. A., Bridges B. K. and Hayek J. C., (2006), *What matters to student success: a review of the literature*, Washington, DC: National Postsecondary Education Cooperative.

Kuh G. D., Cruce T. M., Shoup R., Kinzie J. and Gonyea R. M., (2008), Unmasking the Effects of Student Engagement on First-Year College Grades and Persistence, *J. Higher Educ.*, **79**(5), 540–563, DOI: 10.1080/00221546.2008.11772116.

Kuh G. D., Kinzie J., Buckley J. A., Bridges B. K. and Hayek J. C., (2011), *Piecing together the student success puzzle: research, propositions, and recommendations*, ASHE Higher Education Report, John Wiley & Sons.

Langemann D., (2014), Kompaktstudium Mathematik für Ingenieurwissenschaften an der Technischen Universität Braunschweig [Compact studies in Mathematics for Engineering Sciences at the Technical University of Braunschweig], in Bausch I. *et al.* (ed.), *Mathematische Vor- und Brückenkurse. Konzepte, Probleme und Perspektiven*, Wiesbaden: Springer Spektrum, pp. 277–294, DOI: 10.1007/978-3-658-03065-0.

Maltese A. V. and Tai R. H., (2011), Pipeline persistence: Examining the association of educational experiences with earned degrees in STEM among US students, *Sci. Educ.*, **95**(5), 877–907.

McLaughlin J., Khanova J., Persky A., Hathaway N. and Cox W., (2017), Design, Implementation, and Outcome of a Three-week Pharmacy Bridging Course, *Am. J. Pharm. Educ.*, **81**(7), 1–6.

Mitchell I. and de Jong E., (1994), Bridging Courses in Chemistry and Physics for Engineering Students, *Higher Educ. Res. Dev.*, **13**(2), 167–178, DOI: 10.1080/0729436940130207.

Parchmann I., Busker M., Klostermann M., Herzog S. and Huber A., (2011), Nicht nur Schulwissen auffrischen: Vorkurse in Chemie [Not just refreshing school knowledge: Pre-courses in Chemistry], *Nachr. Chem.*, **59**, 684–688.

Pascarella E. T., Pierson C. T., Wolniak G. C. and Terenzini P. T., (2004), First-generation college students: Additional evidence on college experiences and outcomes, *J. Higher Educ.*, **75**(3), 249–284.

Poladian L. and Nicholas J., (2013), Mathematics Bridging Courses and Success in First Year Calculus, In Proceedings of the 9th DELTA Conference in Teaching and Learning of Undergraduate Mathematics and Statistics, pp. 150–159.

Rozek C. S., Svoboda R. C., Harackiewicz J. M., Hulleman C. S. and Hyde J. S., (2017), Utility-value intervention with parents increases students' STEM preparation and career pursuit, *Proc. Natl. Acad. Sci. U. S. A.*, **114**(5), 909–914, DOI: 10.1073/pnas.1607386114.

Schmid S., Youl D. J., George A. V. and Read J. R., (2012), Effectiveness of a Short, Intensive Bridging Course for Scaffolding Students Commencing University-level Study of Chemistry, *Int. J. Sci. Educ.*, **34**(8), 1211–1234, DOI: 10.1080/09500693.2012.663116.

Schwedler S., (2017), Was überfordert Chemiestudierende zu Studienbeginn? Eine qualitative Analyse zur Ausprägung des Stresserlebens und Ursachen der Fehlbeanspruchung im Studium der Chemie und chemienaher Fächer [What overwhelms chemistry students at the beginning of their studies? A qualitative analysis of the stress experience and the causes of the stress misuse in the study of chemistry and chemistry-related subjects.], *Z. Didakt. Naturwiss.*, **23**, 165–179, DOI: 10.1007/s40573-017-0064-5.

Teo A. R., Harleman E., O'Sullivan P. S. and Maa J., (2011), The Key Role of a Transition Course in Preparing Medical Students for Internship, *Acad. Med.*, **86**(7), 860–865.

Trusty J., (2002), Effects of high school course-taking and other variables on choice of science and mathematics college majors, *J. Couns. Dev.*, **80**(4), 464–474.

Warburton E. C., Bugarin R. and Nunez A.-M., (2001), Bridging the Gap: Academic Preparation and Postsecondary Success of First-Generation Students, Statistical Analysis Report, Postsecondary Education Descriptive Analysis Reports.