Enhanced teaching and learning outcomes from restructuring a basic organic chemistry course

Jørn H. Hansen*, Annette Bayer*, and Marius M. Haugland*

Department of Chemistry, UiT The Arctic University of Norway

ABSTRACT: The first course in organic chemistry is tough for many students, and motivation may be an additional serious problem if you are taking the course as a part of your study program but do not intend to become a chemist. The combination of long, speedy traditional lectures, complicated material and the use of an important new language (electron flow arrows) does not contribute to easing the cognitive load and may often lead to students giving up very early on. How can we enhance learning outcomes for all students and improve on our teaching practices without compromising the course quality? The basic organic chemistry curriculum and teaching activities at our university have been restructured to allow the students to practice and learn the mechanistic language before chemical reactions. Traditional lectures have been replaced with a cooperative learning-intensive flipped-classroom model. The initial experiences are beyond expectations, and we report a considerable drop in exam failure rate and overall improved satisfaction with the course, both by students and teachers alike.

Keywords: flipped classroom – organic chemistry – mechanistic patterns – constructive alignment – active learning

1 INTRODUCTION

Traditionally, organic chemistry teaching is conducted according to structure and functional group logic. Most contemporary textbooks are still structured this way and virtually neglect pedagogical progress in the field over the past 25+ years including a significant body of accumulated evidence of limited learning.[1] This is a remnant from the past when the discipline was primarily taught according to the empirical scientific advances in the field. This has some advantages though, such as a good organization of transformations and reagents according to functional groups – a sort of synthesis strategy organization. However, this approach is dissonant with the current understanding of how learning occurs and, the general notion persists that organic chemistry is a “hard” subject to pass (and virtually impossible to master) at the introductory level.[1] Perhaps an alternative organization of the curriculum and approach to teaching the introductory level organic chemistry is needed.[2,3] Furthermore, a meta-study by Freeman and co-workers demonstrated how exam performance is improved by 6% in active learning classrooms and that it becomes 1.5 times less likely to fail the final exam in comparison with lecture-only classrooms.[4] These results have really set active learning at the center stage of STEM-education over the last decade.

Several studies have demonstrated how most students do not reach a deep understanding of concepts in organic chemistry and have difficulty mastering the important electron-flow arrow notation.[1,5] Even though the “curly arrow” notation is well-known to organic chemistry (100th anniversary in 2022[6]) and has been commonplace in textbooks for a long time, it has only recently gained traction as a systematic pedagogical tool and as a unifying element for enhancing learning in introductory organic chemistry.[1-3] This formalism has even been employed more recently with great success for enhanced understanding of inorganic reactivity,[7] albeit tragically late. The great advantage of electron-flow arrows is that the students can construct advanced concepts in a systematic manner with increasing levels of difficulty according to patterns of mechanisms, which suggests a unifying organizational curriculum structure. Flynn and co-workers at the University of Ottawa have extensively described how they redesigned a basic organic chemistry curriculum to address issues pinpointed in the literature and to incorporate contemporary pedagogies for improved student learning (and the effects of these changes).[3,8-10] These studies, and a detrimental record of exam failure rates over the past decade at our department, became the impetus for this work where we have introduced a truly student-centered, active-learning approach to our introductory organic chemistry course, moving away from the traditional 2+3 hr lecture-seminar duo (which clearly caters to a transmission view of learning). Moreover, the curriculum has been re-organized according to mechanistic patterns rather than functional groups, with explicit focus on mastering the electron-flow arrow formalism as the unifying language of organic chemistry.

In this study, we have investigated the following research question: *Can we improve student satisfaction and learning outcomes in our basic organic chemistry course by restructuring the curriculum and revising teaching/learning strategies according to contemporary knowledge of what impacts student learning?* Our current understanding of, and reflections on, the four-year impact of major interventions in teaching strategy and learning approaches at our department are the subject of this paper.

2 METHODS

Description of revised course. The revised course is modelled closely after what has been described by Flynn and co-workers.[2,10] The standard 45-minute lecture is no longer performed in the course. Instead, the theoretical background is available through assigned reading materials and a selection of video lectures provided on the course learning platform (Canvas). The video lectures are typically short (10-25 minutes) and focused on small, specific topics. A few lectures have been made in house, but the majority have been sampled from internet resources (Alison Flynn, Leah4Sci, KhanAcademy, Professor Dave and more). The major teacher-student contact time was realized through joint classroom learning sessions (6 hrs/week). The focus was placed on group work on module-specific group exercises (cooperative learning). The group exercises were constructed in a strictly logical manner and are akin to guided-inquiry problems (but less strictly organized), in which the initial problems are very basic and the concepts have been broken down into their smallest units with supporting explanations. The set then gradually builds up complexity until relatively complicated exam-level problems appear at the end and multiple concepts must be integrated. The students carefully construct knowledge when working through these problems, with a minimum of two facilitators (teacher and teaching assistant) rotating between groups (most students partner up with one or more people), answering questions and actively intervening when issues are spotted. The sessions are occasionally intervened by planned or *ad hoc* micro-lectures on topics that are found particularly difficult in the session, or as small introductions to new topics. Seminars (2 hrs/week) were offered initially in which "classical" problems from the textbook and old exam questions were assigned, however, these were discontinued in 2020. Digital self-assessment exercises were developed for each module in 2019 using MasteringChemistry, a software with self-correction capabilities in which structures and electron arrows could be incorporated. These were mandatory and the students had multiple trials available to pass. This tool was not very well developed (technical issues) and was discontinued in 2020. Digital low-stakes multiple choice self-assessment exercises in Canvas will be introduced in spring 2023.

Analysis of summative assessment over time. It was anticipated that a true increase in competency of the students should be reflected in an increase of grade average and a decrease in failures. An analysis of final exam grades during the period 2010-2022 was conducted, in which grade categories Fail, D-E and A-C were quantified, to probe observable effects of the new course structure and teaching strategies. The years 2010-2018 (old format) were averaged, whereas years 2019 through 2022 have been made explicit for comparison.

Analysis of student feedback. The impact of the revised course was further probed by semi-structured interviews with the students, as well as likert-scale and written feedback evaluations on specific aspects of the course. Large differences in participation rate in the evaluations made it difficult to compare directly between the all the four years and only those with a large participation rate are included.

Teacher´s assessments. The qualitative observations made by the teachers (both course responsible and teaching assistants) were documented periodically since the implementation of the new format and, used for improvement adjustments continuously. Teacher assessments of how the new format has impacted teaching practice, student learning outcomes and student/teacher satisfaction have been analyzed to further support the claims in this paper.

3 RESULTS AND DISCUSSION

Student activities. Student engagement with the intended learning outcomes (ILOs) appeared to be sparse in the first year of implementation (2019) and only 28% of students reported using these. The ILOs are crucial to a student-centered approach, though, since they direct both assessment tasks and the teaching/learning activities.[1,2] This was thoroughly emphasized and communicated to the students periodically over the three subsequent years. In 2021, 84% of the students reported that they had worked on the ILOs. Thus, student awareness and engagement with the ILOs appeared to be increasing.

Student engagement with the teaching and learning activities also increased over time. The video lectures and recommend readings were used by 38% and 52% of students, respectively, in 2019. Already in 2020, the equivalent numbers were 74% and 82% - a distinct increase. The internet videos needed quality control, and the students typically reported dissatisfaction with certain video types (e.g. from KhanAcademy). However, there does not seem to be a need to generate a complete in-house lecture set. A lot of effort was required to identify a contemporary textbook with the appropriate pedagogical quality and organization. Some students promoted the use of a new Norwegian textbook but, unfortunately, this still retains the classical core structure and was therefore deemed substandard.

The students were initially satisfied (81%) with having a mandatory digital self-assessment element in the weekly workflow but, technical challenges prohibited its use, and it was discarded in 2020. The purpose of this formative assessment is steadily anchored in enhancing metacognition so that students become aware of their learning status in each module and can respond accordingly. From 2023, low-stakes digital multiple-choice tests will be available for self-assessment of learning in Canvas.

Despite having worked on a topic through the digital tasks, most students spent a lot of time on the initial stages of the corresponding group problems. In 2020, group exercises became mandatory individual hand-ins every week – a change which increased both participation and completion of the sets. Despite the perceived drastic increase in workload by the students, 84% reported spending between 9-15 hours per week in total on the course in 2021, which is appropriate for 10 ECTS. Perhaps lecture-focused courses (with accompanying reduced learning outcomes) feel less tough since the students are not actively engaged in the learning to much extent. 79% of the students reported that the group work gave them improved learning outcomes,[11] which is very much in line with findings by Foldnes who reported that cooperative learning is crucial in a flipped-classroom in order to significantly enhance academic performance.[12]

Seminars were sparsely attended in 2019 and, since in early 2020 virtually nobody showed up (reportedly due to time constraints), it was decided to discontinue these. Recorded video solutions for the seminar problem sets were developed instead, which appeared to be satisfactory. The concern that the students would not be exposed to exam-level questions in their training was addressed by adding several such problems to the group exercise sets.

The isolated impact of change in curriculum organization is difficult to assess. However, there was an observable improvement in competencies of the students in using the electron-flow notation during the written exam in 2019. The same was observed in subsequent years in the mandatory written hand-in exercises. It is reasonable to anticipate that this must be a supporting factor for understanding the reactions part of the curriculum and the ease in cognitive load was somewhat visible from student feedback and observations during classroom activities. Our findings are very much in line with those of Webber and Flynn who have extensively characterized student work and problem-solving strategies in a very similar course format. They were able to demonstrate higher success rates, although a causal link could not be concluded.[8]

Final exam. In 2019, the summative assessment was a traditional written school exam. In comparison to the 8-year average exam results from 2010-2018, during which a strictly traditional lecture+seminar curriculum model was operating, the results were staggering (Fig. 1). The percentage of exam failure was reduced by 32%. If you just compare to 2018, the amount of failures dropped by 46% to 2019. The grades generally shifted more towards the lower and mid-scale (C-E) whereas the number of top grades (A-B) remained unchanged. The skill and competency levels observed at the end of the course (e.g. electron-flow arrow notation in the written exams) were clearly improved from previous years. The approach described by Antonsen et al. bears many similarities to our study, and they report similar findings.[13] Convincingly, the observed significant improvements in summative assessment outcomes are likely because of the interventions we have made in teaching and learning practices.

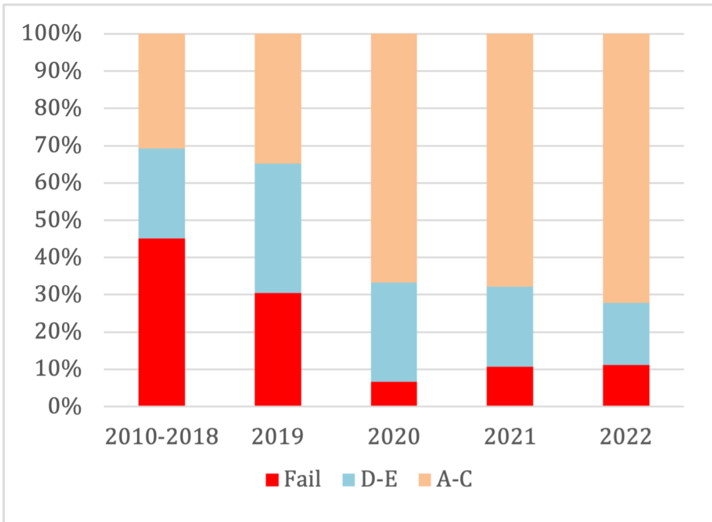

Fig. 1. Final exam grade distribution in KJE1002.

The exam format had to drastically change in 2020 due to the onset of the pandemic and it was decided to test out oral final exams despite the relatively large number of students (ca 40 in 2020). As such, a direct comparison between 2019 and 2020-2022 is procluded by several convoluted factors. Nevertheless, we observed further decrease in the amount of exam failures and the level appears to have stabilized at ca 10%. There is a significant shift towards achieving the grade C in years 2020-22, whereas the number of top grades A and B remain virtually unchanged. This observation could suggest that the apparent improvements are due to a real increase in competencies of the students, and not just an effect of changing the exam format or "lowering the fence". The exam format is evolving, and we are working further on improving the quality of assessment.

Student feedback comments. Overall, the students were positive towards the revised course model and saw the value of active learning. E.g. in 2020, only 7% of the feedback comments were directly negative, whereas 68% reported a positive experience. In 2021, 71% of the students gave distinct positive comments on the course format. Many statements also reflect positive changes for students and even how they "discovered" great learning outcomes (translated into English): *"I learned more than through the traditional lectures. It´s pretty logical that you learn more when you solve problems." "With the old lecture format, the course became overwhelming fast. After a while we were not able to follow the slides and gave up!"*. "*It´s super! (...) the new way of doing things gives me a greater learning outcome, especially in this subject. We have to draw and discuss to understand – active work is important to master this.". "Sceptical in the beginning. I like lectures, but I can see that the practical approach was more valuable"*. And some comments confirmed that the mission on active learning was working: *"(...) I notice that lecture-free teaching only leads to less work for the teacher and more work for each student"*. Some students expressed positive experiences and improved learning outcomes due to the large amount of mandatory in-class work. Many pointed out that the requirements of progression and high expectations had been really good for them, particularly in conjunction with a lot of feedback during classroom sessions from both teachers and peers. The level of satisfaction was high and in line with what has been reported in other studies.[1,2,8,10]

Teacher perspectives. The role as an active facilitator of learning has been rewarding and a very positive experience. Teaching has become more enjoyable and a considerable increase of 1:1 interaction has enabled better follow-up of student learning and more possibilities to intervene when problematic topics arise.[14] The possibility to more closely observe student problem solving "live" has enabled us to provide personalized feedback and support on activities and learning progress – highly valuable information for the metacognitive aspects of learning enhancement. The student-teacher relations have become closer which has led to a much-improved understanding of what the students are struggling with, which in turn provide the topics for *ad hoc* micro-lectures during classroom hours or new video lectures. The revised teaching methods seems to improve student learning and changes the teacher focus and time usage more towards what the student actually does rather than presentation techniques and slide preparation. One considerable advantage has been that the teacher really gets deep insight into student thinking, in stark contrast to the traditional lecture format where little or, at best, only superficial information can be extracted.

4 SUMMARY AND CONCLUSIONS

In summary, we have re-designed the introductory organic chemistry course curriculum at the UiT Department of Chemistry and strongly emphasized active learning and alignment between intended learning outcomes, student activities and assessments and, have completely discarded the traditional lecture-seminar model. We observe a significant improvement in final exam grades and reduction of failures, more actively engaged and satisfied students, closer interaction and feedback between students and teachers, and improved satisfaction among the teachers because of a reorientation of focus towards student learning rather than classroom performances. We are continuously improving our revised course format and look forward to reporting the longer-term effects on these interventions.

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