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Article

Weekly Cumulative Quizzes in Organic Chemistry

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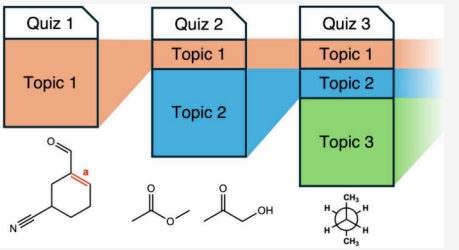
ABSTRACT: A challenge in organic chemistry as well as in other subjects is that a set of fundamental skills is required to master more advanced topics. In an attempt to force students to invest in learning fundamental concepts before working with more advanced topics, we have introduced weekly compulsory quizzes and associated practice tests in our introductory organic chemistry course. The weekly quizzes are *cumulative* in the sense that the students are tested on the current *and all previous* topics in each quiz. The aim of the present work is to motivate, describe, and discuss the implementation of these weekly cumulative quizzes and to gain insight into how their use may benefit student learning in the subject. In particular, we seek to disentangle *preference* and *perceived learning* when it comes to students' perspectives on the cumulative and frequent nature of the quizzes. We analyzed the use of the weekly cumulative quizzes as well as the practice tests and obtained students' perspectives through evaluation surveys. Usage statistics (from 16 students) indicate that the cumulative quizzes force the students to engage with all previous topics every week, whereas the practice tests that are associated with each topic are mostly used in the week the topic is introduced. Importantly, the students are convinced that the cumulative nature of these quizzes is beneficial to their learning. We document not only a perceived learning benefit (*Which do you think is best for your learning?*) but also a preference (*Which do you like best?*) among students for cumulative quizzes vs noncumulative quizzes as well as for weekly quizzes vs quizzes every 2−4 weeks. Despite the low number of students in the present study, weekly cumulative quizzes seem to be a promising tool to build fundamental skills in organic chemistry and other subjects.



KEYWORDS: *Formative Assessment, Question Banks, Multiple-Choice, Organic Chemistry, Online Quizzes, Reaction Mechanisms, Automated Assessment*

INTRODUCTION

Organic chemistry is a part of the curriculum of several university science degrees. Among students, both of chemistry and of other disciplines, the subject of organic chemistry has achieved a reputation for being difficult and demanding.[1] Many reasons for this have been proposed. The large amount of material typically covered in an introductory organic chemistry course can be overwhelming to some students. For historical reasons this material is often organized by functional group, in a system that can in itself be a barrier to student learning.[2] Moreover, organic chemistry is taught and practiced through a symbolic language, using abstract representations of molecular structure and reaction mechanisms that represent an additional challenge.[3,4] Although the subject requires students to use higher-order cognitive abilities (e.g., abstract, analytical thinking and three-dimensional visualization), rote memorization has frequently been found to be a central learning strategy chosen by organic chemistry students.[1,2,5,6] This is especially the case when students do not achieve sufficient skills and understanding of the fundamental concepts, e.g., the "curly arrow" formalism, before proceeding to more advanced topics such as multistep reaction mechanisms.[7] Conversely, taking the time to identify the underlying principles and focusing on learning fundamental concepts has been found to improve student learning and morale, and decreased the perceived importance of rote memorization.[7,8] Connecting this solid foundation with a mechanistic approach to organic chemistry can liberate the capacity to address organic chemistry at the higher cognitive levels required to excel in the subject.[9]

Careful curriculum design and in particular effective assessment can contribute to solving the challenges in learning a demanding subject. Research on how we learn has clearly established that some learning strategies are more effective than others.[10] In particular, *practice testing*[11,12] and scheduling study activities over time (*distributed practice*)[13,14] are learning strategies that have been proven to be effective across different types of learners, different to-be-learned material, different ways of learning as well as across different ways to measure learning.[10] Among the various ways of combining the benefits of practice testing and distributed practice is cumulative quizzing throughout the semester.[15−17] In a cumulative quiz, students are tested on all material they have been introduced to up to the point of that particular quiz. When cumulative

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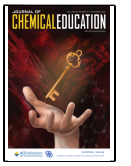

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quizzes are taken regularly, they necessarily lead to repetition and spacing of previously learned material. Whereas a cumulative final exam is common, cumulative quizzes throughout the semester are not. The present work is inspired by the work of Stowell, who has advocated cumulative quizzes and described an implementation in an upper division psychology course.[15] In his approach, the quizzes are not only cumulative, but also incremental, i.e., with an increasing number of questions from one quiz to the next. We note, however, that others have documented an incremental cumulative quizzing scheme before.[18]

Implementations of cumulative quizzes throughout the semester have been reported various fields such as psychology,[15,16] biology,[17,19] medicine,[18,20] mathematics,[21,22] pharmacy[23] and second language acquisition.[24,25] This has given some insight in the effect of cumulative quizzes on student learning, but important questions remain unanswered. Lawrence found that three cumulative quizzes throughout the semester improve retention of the material in an introductory psychology course compared to a control group with the same number of noncumulative quizzes.[16] Those who took cumulative quizzes performed better on the exam as well as on a follow-up test two months after the exam.[16] Beagley and Capaldi performed a similar study with three semester tests in a mathematics course and also found that students exposed to cumulative semester quizzes benefit from this in the final exam.[22] Bailey et al. introduced weekly cumulative quizzes in an introductory biology course.[19] Even though they documented improved exam performance after their course revision, their study did not answer to what extent the cumulative quizzes or other components of their revised course where responsible for this increased performance.[19] Kerdijk et al. investigated how cumulative assessment affected self-study in a randomized controlled study with medical students.[18] They found that students that were assigned three incremental cumulative quizzes during a course spent substantially more time on self-study than students in a control group that was assigned one single cumulative final exam. The study design did not allow the researchers to disentangle the effects of the frequency and the cumulative nature of the quizzes.[18] To disentangle these two effects, Bailey et al. later performed a quasi-experimental study where seven cumulative quizzes were administered in one section of an introductory biology course and seven noncumulative quizzes in another section that was otherwise identical.[17] They did *not* find an overall increased performance for the students in the cumulative section on the final cumulative exam or in a retention test five months later. One possible explanation is that the cumulative nature of the quizzes has no large added benefit when quizzes are administered frequently.[17] Students in both groups who returned for the retention test five months later did, however, think that cumulative quizzes are beneficial for retention of the course content.[17] The issue of student perceptions of cumulative quizzes is relevant as it is likely to influence student engagement and motivation. Wheres the students in Lawrence's study preferred noncumulative tests,[16] Bailey et al. did not find any adverse effects even though this issue was not investigated specifically.[19] Guirguis et al. investigated student perceptions toward cumulative case-based quizzes in two pharmacotherapy courses and documented positive perceptions.[23] However, they did not specifically investigate student perceptions of the *cumulative nature* of the quizzes either, and hence their study does not shed light on this particular issue.

Implementations of cumulative quizzes in chemistry have to our knowledge not yet been documented. We here describe our introduction of weekly cumulative quizzes in an introductory organic chemistry course, aiming to force students to invest in learning fundamental concepts before applying them to more advanced topics such as multistep reaction mechanisms. The aim of the present work is to motivate, describe and discuss the implementation of these weekly cumulative quizzes and to gain insight in how their use may benefit student learning in organic chemistry. In particular, we seek to disentangle *preference* and *perceived learning* when it comes to students' perspectives on the cumulative and frequent nature of the quizzes.

METHODS

Over one hundred (N = 108) question banks were developed, aligned to the intended learning outcome of the first 11 (out of 15) topics in the introductory organic chemistry course at UiT The Arctic University of Norway. The question banks were used in compulsory cumulative quizzes as well as in practice tests. Data for the present work consist of usage statistics for the cumulative quizzes and practice tests (sampled in Spring 2023) as well as students' perspectives obtained through end-of-term course evaluations (sampled in Spring 2023 and Spring 2024). Details on the course, the cumulative quizzes and the practice tests are provided below. Details on the question banks—including strategies for development and example items—as well as details on the data sampling are provided in the Supporting Information (SI).

Organic Chemistry Course

Most students in the introductory organic chemistry course are chemistry, biotechnology or preservice teacher students. All students have taken the same course in general chemistry, which has been described previously in this journal.[26] The introductory organic chemistry course is given every Spring and consists of 15 topics (Table S1 in the SI) with one new topic every week, each of which is associated with either a compulsory quiz or a compulsory hand-in assignment. In addition, a practice test is associated with topics 1−11. The practice tests and compulsory quizzes are automatically assessed whereas the hand-in assignments are manually assessed with the help of rubrics. The six hand-in assignments (topics 7−8 and 12−15) consist of drawing reaction mechanisms. During the semester, the focus gradually shifts from learning fundamental concepts in organic chemistry to gaining mechanistic insight in organic reaction mechanisms, including multistep synthesis. This change is reflected in a shift from cumulative quizzes in the beginning of the semester to more hand-in assignments at the end of the semester. The structure of the course was inspired by the work of Flynn and Ogilvie[2] and follows the textbook by Ogilvie et al.,[27] approaching organic chemistry from a mechanistic perspective. Hence, fundamental principles of reaction mechanisms and the electron-pushing formalism are introduced before introducing specific reactions. Reaction mechanisms are introduced in order of increasing difficulty,[2] corresponding to the structure in the textbook.[27]

The course uses a flipped-classroom approach[28,29] with intended learning outcomes, video lectures and other resources available through the learning management system. Classes in the course (6 h per week) are student-active, compulsory to attend and supervised by the course leader and/or one

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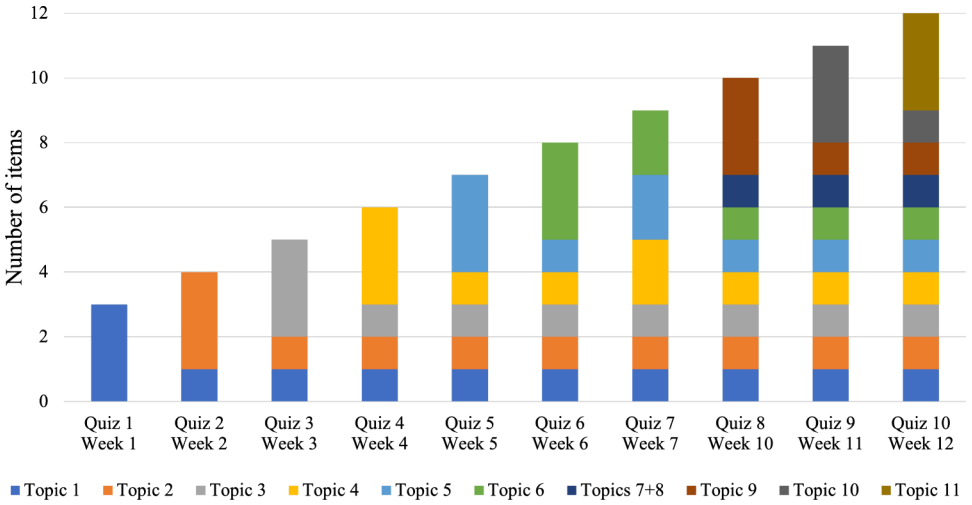

Figure 1. Weekly cumulative incremental quizzes in organic chemistry. Note that quiz 7 in week 7 is a repetition of the first six topics/weeks and that no cumulative quizzes (but hand-in assignments) are associated with topics 7 and 8 in weeks 8 and 9. See Table S1 in the SI for the list of topics.

graduate teaching assistant. Time in class is mainly devoted to discussing and solving problems in groups. The introductory organic chemistry laboratory course (which also includes spectroscopy) is scheduled in the following semester. Access to the exam is obtained by attending at least 80% of all classes and passing the weekly quizzes and hand-in assignments. Summative assessment of the course is an oral exam lasting approximately 25 min and counting for 100% of the grade. The oral exam consists of questions and discussions around specific molecules and reactions, with students drawing and explaining reaction mechanisms on a whiteboard. The assessment places particular emphasis on students' ability to correctly use central terminology, to explain how molecular structure and electronics influence reactivity, to assess and predict the reactivity of a given molecule (or combination of molecules and reagents), and to correctly use curly arrows to propose reasonable reaction mechanisms. Over the three Spring semesters prior to the implementation of the practice tests and cumulative quizzes (2020−2022), 76 students took the exam out of which 69 passed. This corresponds to an average of 25 students per year and a pass rate of 91%. The average grade was C in each of those years.

Cumulative Quizzes

The ten cumulative quizzes consist of three questions on the present topic in addition to one question on each of the previous topics (Figure 1). The weekly quizzes are thus *incremental* in size—starting with three questions in the first week and extended by one question every week—and *cumulative* in the sense that all previous topics are repeated in each quiz. Students were given 5 min per question in the first implementation of the quizzes (Spring 2023). Hence, the time available for taking the quizzes is also incremental from 15 min for the first quiz to 60 min for the last quiz. In the first iteration, the average time-on-task per item for the cumulative quizzes gradually increased during the semester from below 2 min per item for the first four quizzes to 3 min per item for the last quiz. In the second iteration (Spring 2024), the time limit was decreased from five to to 3 min per item in an attempt to stimulate practice with the current and previous topics *before* taking the cumulative quiz. The average time-on-task per item was approximately 2 min for all quizzes in the second iteration.

Each item is awarded one point, with some items allowing for partial credit (see the SI for example items). Students are given three attempts to pass the quiz (minimum 80% correct) and are advised to use practice tests—which have neither a time limit nor a limited number of attempts—in preparation for the compulsory quizzes. With the exception of quiz 2, it was possible to reach the passing threshold without obtaining the full score. Quiz items related to the topic covered during the same week as the quiz are included as the first, third and fifth questions. The obvious exceptions are the first two quizzes, which contain fewer than five questions. All other items in a particular quiz are taken from previous topics. For this purpose, ten items from a series of 4−7 relevant question banks were copied into one dedicated repetition question bank per topic. Thus, all relevant items from all previous topics can potentially be drawn on each of the compulsory weekly quizzes.

Notable differences with Stowell's implementation of incremental cumulative quizzes[15] are that the quizzes in the present work do not count toward the final grade and that we have not attempted to equal the number of items from each topic over the range of the entire semester. As a result of this, the cumulative portion of the quizzes ranges from 25% for the second quiz to 75% for the final quiz in our implementation. For comparison, the cumulative portion of the quizzes ranged from 18% for the second quiz to 42% for the final quiz in Stowell's implementation,[15] whereas the cumulative portion of the exams was 20%, 20% and 55% for the second, third and fourth exams, respectively, in Lawrence's implementation.[16] About half of the items in the midterm exams from Bailey et al. came from previous topics.[17] The cumulative portion of the quizzes in the present work is thus larger than in some of the previously published cumulative schemes.

Practice Tests

One practice test was made for each of the first 11 topics in the organic chemistry course. The practice tests of topics with associated cumulative quizzes (topics 1−6 and 9−11) contained 12 items. The practice tests of topics 7 and 8—which were associated with hand-in assignments rather than cumulative quizzes—contained 6 items. All items on the practice tests were drawn from the described question banks,

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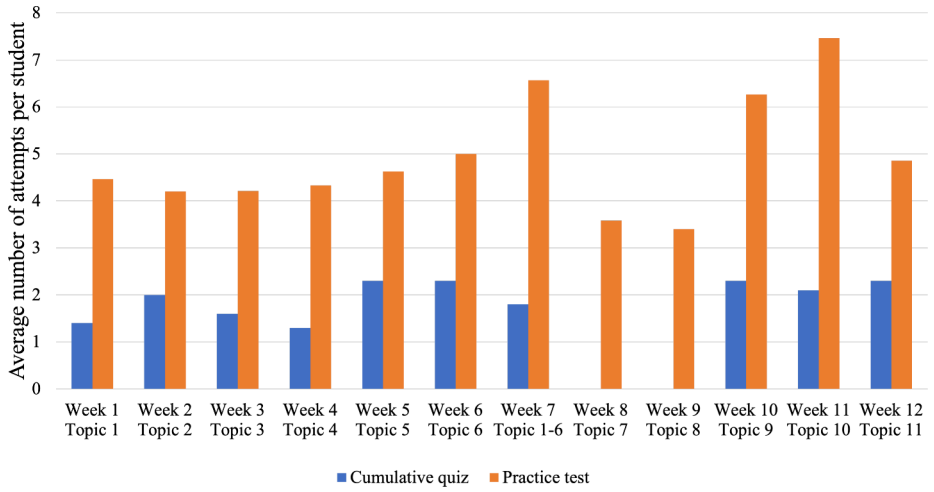

Figure 2. Average number of attempts per student taking at least one attempt for the cumulative quizzes (blue) and practice tests (orange).

Table 1. Number of Attempts Throughout the Semester on Practice Tests Associated with Topics 1−6[a]

	Attempt Taken in Week[b]									
	1	2	3	4	5	6	7	8−17	18−20	Sum
Topic 1	**40**	0	0	0	0	2	5	14	6	67
Topic 2	0	**37**	0	3	0	4	7	6	6	63
Topic 3	–[c]	0	**44**	2	0	2	1	6	4	59
Topic 4	–	–	0	**36**	2	6	3	16	2	65
Topic 5	–	–	–	0	**41**	3	7	11	12	74
Topic 6	–	–	–	–	0	**35**	13	10	2	60
Sum	40	37	44	41	43	52	36	63	32	388

[a]A week is counted from Monday to Sunday. Due dates for practice tests and compulsory quizzes were on Thursday and Friday, respectively. [b]Weeks 1−6: fundamental concepts; week 7: repetition; weeks 8−17: continued classes; week 20: exam. [c]A dash in the table indicates that the test was not yet available to the students.

thus allowing multiple attempts with a different set of similar items (see the SI for example items). The practice tests associated with topics 1−11 contained mainly items from question banks designed specifically for that particular topic and are hence *noncumulative*. In addition to the 11 topic-specific practice tests, two cumulative practice tests were made on topics 1−6 and 1−11 with 6 and 11 items, respectively. The practice tests had neither a restriction on the number of attempts nor a time limit and were available from one week before the start of the associated topic throughout the rest of the semester. Even though the practice tests were not compulsory, a due date was set as a recommendation to take a first attempt on the practice test halfway through the week in which the associated topic was introduced. In this way, students were stimulated to work with the topic-specific practice tests prior to working with the compulsory cumulative quizzes and hand-in assignments.

RESULTS

We here analyze to what extent students engaged in practice with fundamental concepts in organic chemistry by reporting usage statistics of the weekly cumulative quizzes and practice tests from their first implementation in Spring 2023. We also report students' perspectives from end-of-term evaluation surveys to gain insight in how the use of the quizzes may affect student learning in the subject. Data from the evaluation survey from Spring 2023 were supplemented with data from Spring 2024 due to the low number of students taking the course and as a consequence of that the low number of respondents in the surveys. All 16 students who worked with the weekly cumulative quizzes in Spring 2023 passed the oral exam with an average grade slightly closer to C than B. In Spring 2024, 19 out of 20 students passed the exam with an average grade slightly closer to B than C. We note that the changes in the course from 2022 to 2023 mainly consisted of increased opportunities for formative self-assessment and feedback *outside* classes, as described in more detail the Methods section. Exam results are not further discussed here.

Usage Statistics

A total of 16 students had 305 attempts in total on the cumulative quizzes during Spring 2023. The average number of attempts per student is shown in Figure 2 for the cumulative quizzes (blue) and practice tests (orange).

The average number of attempts per cumulative quiz per student was just below two. Students can have several reasons to use more than one attempt. From the 146 nonfirst attempts at the ten cumulative quizzes in Spring 2023, 119 (82%) were a new attempt necessary to pass the quiz, 25 (17%) were attempts to increase the score for a quiz that had already been passed, whereas only 2 (1%) were a second and third attempt of a student who had already obtained the maximum score on that quiz.

Even though all 16 students who took the compulsory cumulative quizzes also took the practice tests for at least six different topics, the number of students taking a particular practice test varied from 13 to 15 for most tests. The average

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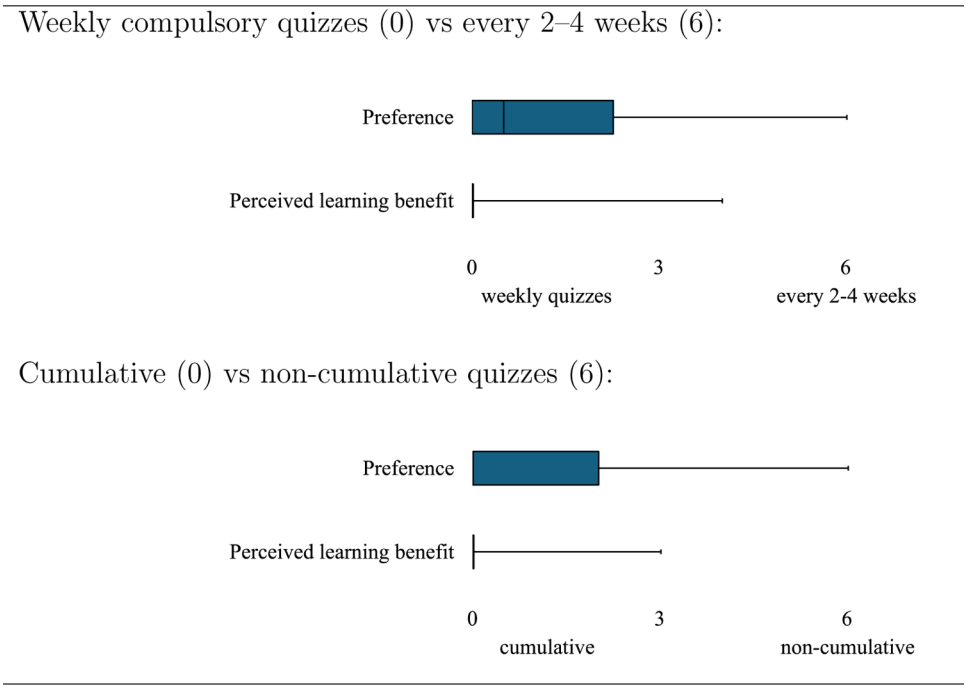
Table 2. Students' Perspectives from Evaluation Surveys[a,b,c]



[a]7 and 9 students responded to the anonymous end-of-term evaluation surveys in Spring 2023 and Spring 2024, respectively. [b]The students were asked to evaluate the perceived learning benefit (*Which do you think is best for your learning?*) and preference (*Which do you like best?*) on a scale from 0 to 6 where 3 is neutral. [c]The interquartile range is shown as blue boxes, the median is given as a vertical line, and the minimum and maximum are shown as whiskers.

number of attempts among students who took at least one attempt (Figure 2, orange) was above four for most practice tests. The practice tests for topics 7 and 8—which had compulsory hand-in assignments rather than cumulative quizzes—were taken by fewer students with a lower average of attempts per student, indicating that the compulsory cumulative quizzes stimulate the use of practice tests at least to some extent. The total number of attempts on all practice tests varied from 6 to 135 for the individual students, with a mean of 54 and a median of 39. Two students had more than one hundred attempts in total for all practice tests throughout the semester.

One major objective with the introduction of the weekly cumulative quizzes was to stimulate practice with fundamental concepts in organic chemistry, which are mainly treated in the first 6 weeks of the course. Previous topics are *directly* revised in each cumulative quiz. In addition, the cumulative quizzes may contribute to more practice *indirectly* through increased engagement with among other things the practice tests from earlier topics. It is therefore interesting to analyze to what extent the practice tests from the first 6 weeks were used throughout the semester (Table 1). The practice tests associated with each topic were mainly used in the week the respective topic was introduced (diagonal elements in bold in Table 1), with some more attempts in or just before the repetition week (week 7), in the second part of the course (weeks 8−17) and in preparation for the exam (weeks 18−20). In fact, two-thirds of all attempts at these practice tests were in the same week the topic was introduced. The 63 attempts in the second part of the course (weeks 8−17) correspond roughly to one student taking each practice tests per week for each of the six tests. These attempts were by seven unique students. The number of attempts at the first six practice tests varied from 3 to 78 for the individual students, with a mean of 24 and a median of 15.

Student Perspectives

Students' perceived learning benefit from and preference for several aspects of the weekly cumulative quizzes were surveyed in end-of-term evaluation surveys in Spring 2023 and Spring 2024 and are presented in Table 2.

The results document a clear perceived learning benefit for quizzes that are given weekly (as opposed to every 2−4 weeks) and cumulative (as opposed to noncumulative). This perceived learning benefit is almost unanimous for both aspects. Interestingly, the results also document a clear *preference* for weekly quizzes and for cumulative quizzes *on average*, albeit not unanimously. In fact, two-thirds of the respondents have a clear preference for cumulative quizzes (0).

Students were asked how the weekly cumulative quizzes changed the way they studied in this course. The following aspects were mentioned among the 12 answers to this question: (i) the weekly cumulative quizzes lead to more, earlier and more efficient repetition of the course content, (ii) the quizzes force the students to work every single week during the course, in a structured manner, (iii) the quizzes help students focusing on the most important part of every topic, and (iv) the quizzes lead to more motivation to work with the course content, including with group assignments and practice tests.

Responses to a set of three statements are presented in Table S5 in the SI and indicate that most students agree that repeating course content leads to less time spent on the course overall, that the quizzes contribute to obtaining necessary basis skills and that the cumulative quizzes lead to more practice with the practice tests. Out of 11 elaborations on the answers

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to the statements, two give insight in the way the students used the cumulative quizzes and practice tests. One student reported practicing with the practice tests until all items were answered correctly at least once. Another student reported taking practice tests to assess whether they understood the course content and—if not—read in the book and took another practice test before attempting the cumulative quizzes. The free-text comments also documented negative aspects of the quizzes: one student reported feeling stressed due to the time limit of the cumulative quizzes (Spring 2024), one student reported a focus on passing the compulsory quizzes rather than meaningful practice due to time constraints and a heavy workload also in other courses, and one student reported a dislike for any activity that is compulsory.

DISCUSSION

We have implemented practice tests and weekly cumulative quizzes in an introductory organic chemistry course with the aim of forcing students to learn the fundamental concepts before applying them to more advanced topics such as multistep reaction mechanisms. A main result of the present study is that the students clearly perceive that cumulative quizzes are better for their learning than noncumulative quizzes. This is in agreement with actual learning outcomes measured by Lawrence[16] and Beagley and Capaldi[22] and a perceived retention benefit by the students in the study of Bailey et al.[17] The students' perception also agrees with the teacher's observations that students indeed seemed to master application of fundamental skills introduced earlier in the course to a larger extent, compared to the years before implementing the weekly cumulative quizzes. On top of the reported perceived learning benefit, students in the present study have a clear *preference* overall for cumulative quizzes. Students in Lawrence's study, however, preferred noncumulative quizzes, leading her to conclude her article with the statement that "it is clear that students do not like cumulative exams, so teachers should make evidence-based decisions about their use".[16] Several factors relating to differences in our implementation of the cumulative quizzes may provide possible explanations for this discrepancy. First, Lawrence had fewer cumulative quizzes (four vs ten in our implementation) with a lower percentage of cumulative items. One might hypothesize that students quickly get used to *regular* cumulative quizzes and that a relatively small amount of extra course content is manageable. In contrast, the added course content of several weeks might feel overwhelming. This is to some extent supported by the observation that the students in this study preferred weekly quizzes over quizzes every 2−4 weeks (Table 2). Second, the cumulative quizzes in our implementation were not graded and are regarded as a *formative* assessment, even though students need to pass the quizzes in order to be able to take the exam. One might hypothesize that students are more favorable toward formative types of assessment. This could also explain why the students in the study of Bailey et al.—where a creative grading scheme rewarding improvement and not penalizing early failure was implemented alongside the cumulative quizzes—were generally favorable to their implementation.[19]

The relation between the usage of the compulsory weekly cumulative quizzes and usage of the topic-specific practice tests is complex and deserves a closer look. Students mostly agreed with the statement that the weekly cumulative quizzes made them take the practice tests more often. At the same time, usage statistics clearly indicate that the practice tests are mostly used in the weeks that the associated topic is introduced and hardly in subsequent weeks where the same content is repeated in the cumulative quizzes (Table 1). The weekly quizzes thus seem to motivate the students to take the practice tests of the *present* topic rather than those of *previous* topics. This is supported by the fact that the number of practice test attempts was lower for topics 7 and 8—which were associated with a hand-in assignment rather than with a cumulative quiz—compared to the weeks before and after (Figure 2). Paradoxically, one could even ask whether the cumulative quizzes lead to *less* usage of practice tests of previous topics, since repeating previous topics is naturally included as part of the weekly cumulative quizzes. Either way, distributed practice with previous topics is known to be beneficial for student learning.[13,14] It seems that students are at least to some extent aware of this since most of them agreed to the statement that they spent less time on the course overall by repeating course content regularly throughout the semester.

A relevant aspect of any attempt to improve the curriculum is the time spent to implement the changes. Development and quality assurance of a large number of question banks is a time-consuming task.[26] The work described here involved the development and quality assurance of over a hundred question banks. We estimate that the development alone of one question bank takes between one and four hours. However, once this work has been done (or when high-quality question banks already are available), making the quizzes by selecting items or question banks is a straightforward task. Importantly, not much time is required to convert a series of noncumulative quizzes to cumulative quizzes. Automatic assessment of the quizzes is time-efficient and independent of the number of students. In fact, using automatically assessed tests can be a time-efficient way to monitor students' achievements and to identify students or topics that need further attention. More generally, automatically assessed tests can—when carefully implemented—be a time-efficient way to encourage student−teacher dialogue around learning and provide feedback to shape teaching.[30] Once all assignments have been developed and implemented, manual assessment of hand-in assignments obviously takes much more time than assessing quizzes automatically, even though rubrics can ease the assessment job significantly. It is thus relevant to discuss the added benefit of hand-in assignments over automatically assessed quizzes. The relevance of this question increases with the number of students in the course. Even though some aspects of reaction mechanisms can be assessed automatically as discussed by Flynn,[31] Ruder and Straumanis[5] and in the present work (Table S3 in the SI), we believe that multiple-choice items or other automatically assessed question types cannot entirely replace manual feedback on actual *drawings* of reaction mechanisms. We will thus continue to balance the use of automatically assessed quizzes and manually assessed hand-in assignments in our courses.

A clear limitation of the present study is the small-scale nature of the course in which the weekly cumulative quizzes have been introduced. Indeed, usage statistics from Spring 2023 are based on only 16 students, and the same number of students responded to the evaluation surveys in total over the course of two consecutive Spring semesters. One should also be aware that usage statistics of digital tests do not give a complete picture of the way students engage with practice of present and previous topics and we have here not attempted to

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quantify for example time spent reading (and rereading) the textbook and other ways of revising course content. Another limitation is that our study only documents a *perceived* learning benefit of both the frequency and the cumulative nature of the quizzes, without attempting to investigate the *actual* learning benefit of each of these factors.

Despite the low number of students in the present study, weekly cumulative quizzes seem to be a promising tool to build fundamental skills in organic chemistry and other subjects. We do not plan any changes in the implementation the cumulative quizzes (Figure 1), but we are implementing a similar approach in other undergraduate courses and consider using the quizzes in some way in the in-class activities. The latter can for example be done by discussing the most difficult items from homework quizzes in class,[28,31] by structuring classes through individual in-class diagnostic polling followed by formative teacher feedback[26] or by teaching through peer instruction[32] with items from the question banks that are best suited to stimulate discussion among the students.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.4c00741.

Topics in the organic chemistry course, description of the question banks with example items, details on the data sampling, and additional results (PDF)

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Notes

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