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Implementation of a Specifications Grading System in Four Upper Division Chemistry Courses

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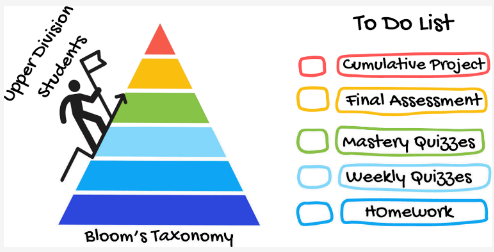
ABSTRACT: Specifications (specs) grading systems use a "checklist" approach to assessing students that asks them to demonstrate a high level of proficiency in course content, often coupled with multiple attempts at revision. Students also must demonstrate mastery in some specs to earn high letter grades. There have been several reports in lower division college chemistry courses that use specs grading systems (e.g., general and organic chemistries), but there remains a dearth of accounts of specs grading systems in upper division courses. In this manuscript, we report on the use of specs grading systems at a primarily undergraduate women's college in four upper division chemistry courses: biochemistry, inorganic chemistry, thermodynamics, and quantum mechanics. The conceptual framework for designing specs tailored to upper division chemistry courses and their use to assess student understanding of course content are shared along with student outcomes and feedback. The upper division students generally had a positive view of the specs grading system with students viewing themselves as working hard on assessments that were tough but fair. Finally, instructor comments are presented in an effort to highlight the perceived benefits and challenges of specs grading to future adopters.



KEYWORDS: *Upper Division, Biochemistry, Inorganic Chemistry, Physical Chemistry, Curriculum, Assessment*

INTRODUCTION

In recent years, alternative grading systems have grown in popularity in chemical education as well as science, technology, engineering, and math (STEM) courses more broadly.[1,2] One of the most popular adaptations has been specifications, or specs, grading systems that replace a traditional points-based grading system with a list of specifications that students must meet to earn certain letter grades.[3−5] The specs are often derived directly from course learning outcomes and students earn credit by showing proficiency and/or mastery in those objectives. Assessment is usually driven by frequent quizzes that have a high standard of passing (typically ≥80%), without awarding partial credit for incorrect answers. Along with these high standards come built-in opportunities for revision without penalty, typically in the form of quiz retake sessions.

Chemical educators have reported the use of specs grading systems primarily in lower-division chemistry lecture courses such as general chemistry and organic chemistry.[6−17] The appeal of the courses at this level is clear: multiple unpenalized attempts at the same content helps to bridge the gap between students who arrive at college with different levels of background in chemistry, and the requirement for high levels of proficiency builds a strong foundation in content knowledge. Instructors have also reported that specs systems make assessment grading more consistent across multiple graders,[16] which can improve equity and student outcomes in large classes that are common in lower-division courses. Much less present in the chemical education literature has been the application of specs grading systems in upper division or graduate chemistry lecture courses.[18−23] In chemical biology, Kelz and co-workers implemented specs grading in an upper division course to improve students' application of foundational knowledge through writing assignments,[21] and Donato and Marsh measured student-perceived and actual learning gains based on mastering learning objectives through multiple attempts at quizzes in the first semester of a two-semester biochemistry course.[20] Specs gradings has also previously been implemented in a one-semester physical chemistry survey course for chemistry and natural science B.A. students with minimal effect on grades but positive student and instructor perceptions;[23] however, specs grading in upper division thermodynamics and quantum mechanics courses for B.S. chemistry majors remains unexplored.

Most undergraduate chemistry curricula take content from lower division courses and explore it in more depth in upper division courses. While content comprehension is still important, it is essential that students are challenged to grow in the application of course content. We believe that the use of a specs grading system in upper division chemistry courses

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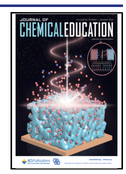

allows for more effective assessment of student learning at the higher levels of Bloom's taxonomy, such as the application, analysis, evaluation, and creation of course content.[24] The "bundling" of assignments in specs grading allows for certain classes of assessments to be "mastery level", while other specs assess student proficiency in learned content. For example, in the specs grading system used in this report, certain quizzes are designated mastery level, and only affect a student's grade between B-level and A-level letter grades. In this report, we present the results and student feedback from the implementation of specs grading systems in four upper division chemistry courses.

■ CONTEXT FOR IMPLEMENTATION

Saint Mary's College

Saint Mary's College is a Catholic, liberal arts college offering undergraduate degrees for women and coeducational graduate programs. There are approximately 1500 enrolled undergraduate students.

The ACS approved chemistry program graduates ∼8−12 students per year and has five tenure-track faculty members and two full-time nontenure track faculty members. Each year, ∼50% of chemistry majors are enrolled in the dual-degree engineering program at the University of Notre Dame. In this program, students receive a B.S. degree in chemistry at Saint Mary's after four years and a B.S. degree in engineering at the University of Notre Dame after a fifth year (typically chemical or environmental engineering). All STEM-intended students enroll in the general chemistry sequence in their first year (if "calculus-ready") or second year. Students intending to major in biology or chemistry continue to the organic chemistry two-semester sequence. Organic chemistry II serves as a prerequisite for upper-level foundational biochemistry and inorganic chemistry, and the "advanced lab" course. Chemistry majors are concurrently enrolled in organic chemistry II and the foundational analytical chemistry course. Our physical chemistry courses, thermodynamics and quantum mechanics, can be taken in any order and have prerequisites of general chemistry II and general physics II.

None of the upper-level courses in analytical, biological, inorganic, or physical chemistries have concurrent laboratories. Instead, chemistry majors enroll in the advanced lab course. The research-based lab course has four modules covering different areas of chemistry across a year. This is typically taken by students in their third year who may or may not be enrolled in the foundational courses concurrently.

Courses in This Study

Biochemistry is a one-semester survey course taught in the Fall that is required for chemistry majors and an elective for the chemistry minor. It covers structure and function of biological macromolecules, membrane structure and transport, glucose metabolism, and ATP synthesis. It is typically taken by students majoring in biology, neuroscience, or other majors who intend to pursue medical or other health-professions school. Therefore, course enrollment tends to be chemistry majors in their third year and other majors in their third or fourth year. The course meets three times a week for 50 min sessions. This course has been taught by the same instructor (author J. Fishovitz) since 2015 using traditional grading until Fall 2023.

The foundational inorganic chemistry course, bioinorganic chemistry, is taught in Fall semesters. It covers the basics of symmetry, bonding theories, coordination chemistry, and spectroscopy, and their applications for metals in biological systems. This is a required course for chemistry majors and an elective for the chemistry minor. This course is typically offered each year and taken by students in their third or fourth year. The course meets twice a week for 75 min sessions. This course has been taught by the same instructor (author M.J. Drummond) since Fall 2022 using the specs grading system described in this study.

Thermodynamics is a one-semester course taught in Fall semester in which students are introduced to the concepts of energy, entropy, heat, and work as they relate to chemical processes such as phase transitions, chemical reactions, and changes in the environment. Further, students learn to derive chemical kinetic equations and assess proposed mechanisms for chemical reactions as well as explain the relationship between the microscopic and macroscopic properties of a physical system. This is a required course for chemistry majors pursuing the biochemistry concentration and an elective for the chemistry minor. Chemistry majors who are enrolled in the dual-degree engineering program take their thermodynamics course at the University of Notre Dame. Depending on enrollment, this course is typically offered every other year and taken by students in their third or fourth year. The course meets three times a week for 50 min sessions. The semester described in this study was the first time the instructor (author L.M. Sager-Smith) taught this course at Saint Mary's College.

Quantum mechanics is a one-semester course taught in Spring semester in which students are introduced to the postulates of quantum mechanics as well as canonical model systems in order to qualitatively and quantitatively understand the origins of quantum numbers, atomic orbitals, molecular orbitals, spectroscopy, and computational chemistry. This is a required course for chemistry majors in the dual-degree engineering program and an elective for other chemistry majors and minors. Depending on enrollment, this course is typically offered every other year and taken by students in their third or fourth year. The course meets three times a week for 50 min sessions. The semester described in this study was the first time the instructor (author L.M. Sager-Smith) taught this course at Saint Mary's College.

The biochemistry and two physical chemistry courses described by this study follow a flipped-classroom approach, with the majority of lecture material being provided to students via lecture videos or reading assignments to be viewed prior to each class session. Students access these preparatory materials via the learning management system (LMS). After a brief review of lecture material at the beginning of each class, the time is spent on peer-mediated instruction through group problem-solving with the instructor providing support and guidance. In the inorganic chemistry course, lecture periods are split between content lectures from the instructor and group work.

In Fall 2023, two of the students enrolled in thermodynamics had taken a specs-based course the previous year. Ten students took two concurrent specs-based chemistry courses in Fall 2023. None of the students were enrolled in all three specs-based courses during that semester. In quantum mechanics in Spring 2024, nine out of the ten students were enrolled in a specs-based course in the previous semester.

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■ IMPLEMENTATION OF SPECS GRADING SYSTEMS

During the 2023−2024 school year specs grading systems were implemented in the upper division courses of biochemistry, inorganic chemistry, thermodynamics, and quantum mechanics. The inorganic chemistry course also used the same specs grading system in the previous academic year. The grading system in each class was based on a previously described hybrid points-specifications grading system used in second semester general chemistry.[10] Each course had a unique set of specifications to earn each letter grade, though they contained similar specifications: 10 weekly quizzes, 4 mastery quizzes, weekly homework, and a cumulative or integrated project (Figure 1).

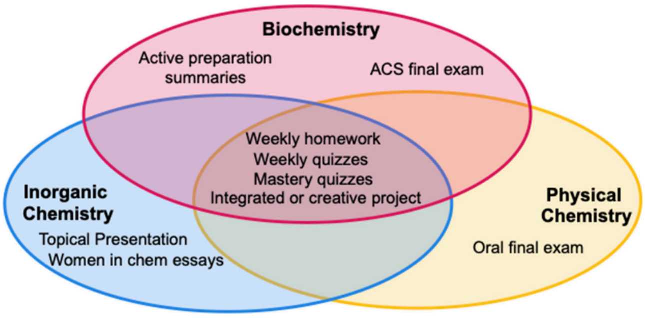

Figure 1. Assessment components for each upper division course. It should be noted that in this study two physical chemistry courses, thermodynamics and quantum mechanics, were offered and used the same set of assessment components.

In each course the homework assignments were used to build foundational knowledge of the topics in the course with assignments being primarily graded on completion and effort. Each course had handwritten homework, outside of biochemistry which used an online platform that allowed for multiple attempts and immediate feedback (Macmillan Achieve). The inorganic and physical chemistry courses had weekly homework assignments that were due 24−48 h before the weekly quiz and graded primarily for effort. Answer keys were posted shortly after so students could correct any misunderstandings prior to taking the weekly quiz.

The weekly quizzes had a high standard of passing (≥80%, no partial credit), but they came with multiple opportunities to pass during designated quiz retake sessions. Individual quizzes and questions were not matched to specific learning outcomes, as some specs courses have done, but were written to assess the previous week's content. Quizzes were typically a mix of 1−2 multiple choice or select all that apply questions, 1−2 conceptual or simple calculation questions, and 1−2 more intricate or complicated calculation questions, and students were typically given ∼15 min to complete the quiz. If a student did not pass a weekly quiz on their first attempt, second or third attempts could be earned through completion of a "token" activity corresponding to each weekly quiz. In biochemistry, tokens were earned through an adaptive assignment administered through the online homework platform. It was only required to earn a third quiz attempt, but was available after the first quiz attempt. In the inorganic course students were given a blank copy of the first version of a quiz and asked to submit a corrected version of the quiz on the clean copy in order to earn a second attempt. In the physical chemistry courses (thermodynamics and quantum mechanics), tokens were administered through the LMS as automatically graded assignments that students must score perfectly on in order to earn the token. In both inorganic and physical chemistry courses, there was no additional token for a third attempt at any weekly quiz.

During a dedicated class period every 3−4 weeks students could attempt a second version of any weekly quizzes from the past 3−4 weeks that they had not yet passed, assuming they had completed the requisite token activity (Figure 2). Mastery

Biochemistry		Q1	Q2	Q3 QR1 MQ1		Q4	Q5	Q6 QR2 MQ2		Q7	Q8	Q9 QR3 MQ3	Q10	QR4 MQ4			ACS Final Exam
Inorganic		Q1	Q2	Q3	QR1 MQ1	Q4	Q5	Q6 QR2 MQ2			Q7	Q8	Q9	Q10		QR3 MQ3	QR4 MQ4
Week #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Thermo-dynamics		Q1	Q2	Q3 QR1 MQ1		Q4	Q5	Q6		Q7 QR2 MQ2		Q8	Q9		Q10 QR3 MQ3	QR4 MQ4	Oral Final Exam
Quantum Mechanics		Q1	Q2	Q3	QR1 MQ1	Q4	Q5	Q6 QR2 MQ2			Q7		Q8	Q9	Q10 QR3 MQ3	QR4 MQ4	Oral Final Exam

Figure 2. Timeline of quiz assessments during the semester. The mastery quizzes and quiz retakes were administered simultaneously during designated class periods. Each quiz retake session presented students with alternate versions of the 3−4 quizzes attempted since the start of the term or previous quiz retake class periods. Some of the quizzes later in the term may move weeks depending on the timing of the Thanksgiving and Easter holiday breaks. Q# = weekly quiz number, QR# = quiz retakes number, MQ# = mastery quiz number. There are no assessments during week 1, and week 9 serves as a midsemester break for our institution during both semesters.

quizzes were administered alongside the quiz retakes, meaning that the more weekly quizzes a student had passed, the more time they had to complete a mastery level quiz. A third attempt at any weekly quiz was offered during the last week of class or during the final exam period, depending on the class.

The mastery quizzes were administered during quiz retake sessions and written as a synthesis of the material covered during the previous 3−4 weeks, or as questions related to an assigned research article. Mastery quizzes and the final projects were only used to differentiate A-level grades from other grades. Only one attempt was allowed on each mastery quiz, but only one or two of the mastery quizzes needed to be passed to earn an A-level grade in the courses, and they were not required to earn any other letter grade (See SI for letter grade specification specifics).

In addition to differentiating A-level grades, the mastery quizzes could be used as "currency" to help students achieve the highest grade possible. The idea of a currency system was first proposed by Noell et al.[10] as a way to encourage student engagement across all specifications, even if they were not able to pass a weekly quiz. The currency system allowed students to exchange a mastery quiz to bolster their lowest achieving specification. In the upper division courses in this study, an expanded currency system was used where mastery level (exceeding A-level) achievements in nonmastery specifications could also be used as mastery quiz equivalents to bolster student grades (Table 1). Instructors calculated the currency exchange for students at the end of the term to give them the best grade possible.

Within each course there was differentiation on other assessment categories (Figure 1). The biochemistry course had (almost) daily "active preparation summaries" that asked students to reflect on prelecture videos and ask questions about what they did not understand. Biochemistry also had a three-part, semester-long "metabolism quest" in which they

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Table 1. Currency Exchange System in Upper Division Courses[a]

Specification	Standard of Achievement	Currency Exchange
	Biochemistry	
Mastery Quiz[b]	Mastery quiz passed	Weekly quiz passed
Metabolism Quest[b]	"Excellent" on mastery quest	Mastery Quiz passed
	Inorganic Chemistry	
Mastery Quiz	Mastery quiz passed	Mastery quiz passed
Weekly Quiz	Quiz passed	Quiz passed
Homework	30/30	+3 points
Metals in Med. Presentation	10/10	+2 points
	Thermodynamics and Quantum Mechanics	
Mastery Quiz	Mastery quiz passed	Mastery quiz passed
Weekly Quiz	Quiz passed	Quiz passed
Homework	30/30	+5 points
Cumulative Project	4/4	+1 point
Oral Final Exam	25/30	+3 points

[a]High achievement in any assessment components in the middle column can be exchanged for an improvement in another assessment components in the right column. [b]Passing a mastery quiz or earning an excellent on the mastery metabolism quest could also be used to increase 1 lower spec.

researched information about an assigned enzyme from central metabolism using online databases[25−28] (see SI for full details, Figures S1−S4). A fourth "mastery quest" assignment was used as the final project for the course, required only for A-level grades or to supplement a lower specification through the currency system. For the final exam, the biochemistry course used the American Chemical Society (ACS) two-semester biochemistry exam.

The inorganic chemistry course served one of the college general education learning outcomes as a "women's voices" course (as these courses took place at a women's college). Because of this, one of the course specs assessed reflection essays from in-class discussions and activities related to women's role in the field of chemistry (see SI for more details). The inorganic chemistry course also had an integrated oral presentation about the use or development of a metallodrug graded using a rubric (Figure S5). The inorganic course did not use a final exam, but used the time to present a creative project related to a topic in inorganic chemistry that was also assessed using a rubric (Figure S6). The only modification to the shared specifications between the courses (Figure 1), was that in the inorganic chemistry course, the third and fourth mastery quizzes were written as questions about a research paper that was distributed to the students a week prior to the mastery quiz. Students could use a paper copy of the research paper with notes and annotations while taking the mastery quiz.

The physical chemistry courses contained the common specifications but opted to give the students an oral final exam scored using a rubric (Figure S8). Students were provided with a set of multipart problems representing a cumulation of knowledge gained throughout the semester that could be asked of them during the oral final exam 2 weeks in advance. During finals week, each student scheduled a thirty-minute appointment with the instructor where they were presented with one of the problems and expected to work through the problem completely "chalk-talk" style, explaining their thought processes and rationales as they went. During this presentation, the instructor asked follow-up questions such as "What type of problem is this?" and "How did you know to take that step?" as well as general questions involving the meanings of chemical terms and jargon. Students were allowed to bring all course materials to this appointment—except worked out answers to the problems—and were encouraged to use them as a resource, with the thirty-minute nature of the appointment requiring students to be familiar enough with the material to be able to quickly and efficiently consult it.

■ STUDENT OUTCOMES

The first attempt at any quiz produced an average of ∼50% pass rate, with a second attempt pushing the pass rate up above 80% of students passing weekly quizzes (Figure 3). After final

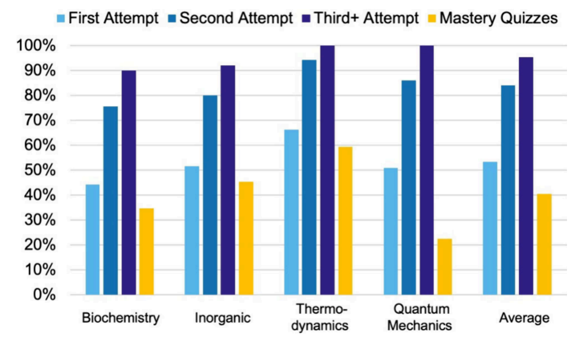

Figure 3. Weekly and mastery quiz pass rates by attempt for all four classes. N = 65 students total, N = 23 in biochemistry, N = 24 in inorganic chemistry over two semesters, N = 8 in thermodynamics, N = 10 in quantum mechanics.

attempts at weekly quizzes, which were done during the last 2 weeks of the term, the average pass rate was at or above 90% for all of the classes. In some cases, students were allowed to retake certain weekly quizzes a fourth time to give them an opportunity to achieve a passing specification grade for quizzes (*vide infra*). This was done at the instructor's discretion and keeps with the foundational grading principles of the system: maintaining a high standard for student learning while offering opportunities for revision. The only cost was writing additional versions of any quiz that required a fourth attempt. Students passed approximately 40% of the mastery quizzes administered, lower than the first attempt at weekly quizzes, signifying the greater challenge of the material (Figure 3).

The currency system (Table 1) was used by instructors to improve student final grades. It is important to note here that the instructors applied currency exchanges that would most benefit the students at the end of the semester and it was not the student's responsibility to make those decisions. Students were provided with information about their final grade and any currency exchanges used so they could ask questions prior to final grades being submitted. The results of the currency exchanges for each course are shown in Table 2. Roughly one-third of the students utilized the currency system to improve their grade in some way, though it was most utilized in the quantum mechanics course. Only 6 students used it to improve their grade to an A-level, when it was not already at that point, and a larger data set needs to be collected to say more about any other patterns in the data.

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Table 2. Currency Exchanges and Their Effects on Letter Grades in Each Course[a]

Students using currency	Exchanging to improve...	Effect on letter grades
	Biochemistry	
10/23 students exchanged MQ or mastery quest	6/10 to raise final exam score 2/10 to replace weekly quiz 1/10 to raise homework spec. 1/10 to raise APS spec.	0/10 students improved to A-level grades from non-A-level grades
	Inorganic Chemistry	
7/24 students exchanged MQ or currency from excellence in HW	4/7 to replace weekly quiz 3/7 to raise the metals in med. spec.	2/7 students improved to A-level grades from non-A-level grades
	Thermodynamics	
3/8 students exchanged MQ or currency from excellence in HW or the final exam	2/3 to earn a MQ equivalence 1/3 to raise final exam score	0/3 students improved to A-level grades from non-A-level grades
	Quantum Mechanics	
8/10 students exchanged MQ or currency from excellence in HW	3/8 to earn a MQ equivalence 5/8 to raise final exam score	4/8 students improved to A-level grades from non-A-level grades

[a]MQ = mastery quiz, HW= homework, APS = Active Preparation Summary. A mastery quiz equivalence is currency exchanged to count as a master quiz to either raise an A− to an A grade, or a B+ to an A− grade.

Mastery of foundational knowledge was also evaluated through final summative assessments in biochemistry, thermodynamics, and quantum mechanisms. The final exam in biochemistry is the ACS two-semester subject exam. This exam has been used as a part of the traditional grading systems in the same course, and no significant increase or decrease in the average score was seen after implementation of specs grading (Figure S9). Oral final exams were used by author L. M. Sager-Smith to probe students' ability to justify their thought processes and reasoning in both thermodynamics and quantum mechanics. As the oral final was meant to assess mastery, these thirty-minute individual exams were only required for students wishing to earn either an "A" grade or a "B" grade in the course. Every student in both classes (8 in thermodynamics; 10 in quantum) attempted the oral final exam, with 33% earning an A level specification (thermodynamics: 3/8; quantum: 3/10), 22% earning an A- level specification (thermodynamics: 2/8; quantum: 2/10), 17% earning a B+ level specification (thermodynamics: 2/8; quantum: 1/10), 17% earning a B level specification (thermodynamics: 1/8; quantum: 2/10), and 11% earning a B- level specification (thermodynamics: 0/8; quantum: 2/10). Overall, the oral final scores skewed higher in thermodynamics than quantum mechanics, which was consistent with the performance on mastery quizzes (Figure 3). Qualitatively, it is noted that performance on the oral final allowed for differentiation between students who grasped the course concepts behind the calculations they were performing and those who were applying equations in a formulaic manner, which can be difficult to assess in heavily mathematical courses such as thermodynamics and quantum mechanics.

■ STUDENT FEEDBACK

End of semester surveys were administered to students to better understand their experiences in the upper division courses using the specs grading systems. Four questions on an agreement scale were used to assess student's general feelings about the course, quizzes, their effort in the course, and if the token activities were useful in helping them to learn material. The combined results for the courses are shown in Figure 4.

Surveyed students generally had a positive attitude about the courses (~89%, Figure 4A) and overwhelmingly viewed themselves as working hard to progress in the courses (~88%, Figure 4C), as has been noted before for upper division chemistry students.[29] The quizzes were largely perceived to be tough but fair (~86%, Figure 4B), though some differentiation was made with regards to mastery quizzes versus weekly quizzes in qualitative responses (*vide infra*). Perhaps most informative was data on how the token activities affected student's perceived learning (Figure 4D). While the vast majority (~84%) of students rated the token activities as helpful to their learning, the biochemistry course was the only one where students said the token activity was minimally or not helpful to helping their learning (Tables S1−S5). This could be because the token activity was administered via an adaptive homework assignment and not written by the instructor (*vide supra*), so it felt disconnected from the students' quiz performance. The instructor also did not explicitly refer to the assignments as tokens, so there may have been confusion about the very nature of the survey question. The biochemistry token activities also contained some information not assessed on quizzes, due to constraints within the homework system, which also may have led to a more negative perception for some students. This is contrasted with the physical chemistry courses that received the most positive feedback for tokens presented as another, more difficult version of the quiz administered and graded through the LMS. It is possible that because these tokens were closest to the actual quizzes, they produced the most positive associations for students, but there is no indication of that in the qualitative responses. One of the inherent limitations of this study is the relatively small sample size of our student population, so data collection will continue further into the future to get a more robust sample.

Students also responded to more open-ended questions about their experiences in each course, with the questions shown in Table S6. When asked about how they could be more successful in the course, the vast majority of respondents said that they would spend more time outside of class studying or attending office hours (Table S12). Some students also mentioned that they would have liked more background or preparation for the courses, or that the courses reduced their anxiety around assessment (Table S15), as some others have

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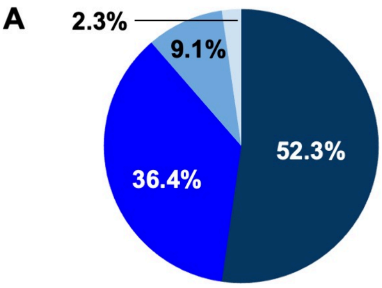
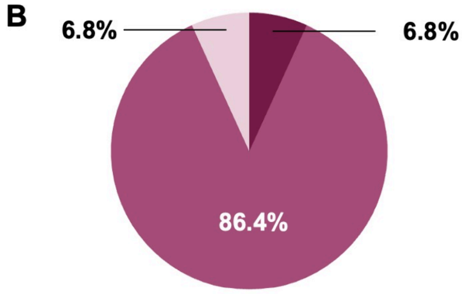
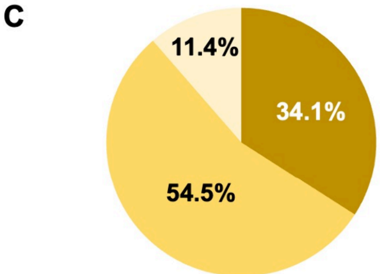


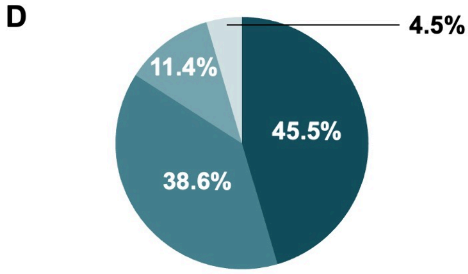
What is your general feeling about this course?	
I feel great! I am learning a lot and doing well in the class.	52.3%
I feel good. I have learned a lot, but know I could do better.	36.4%
I feel okay. I have not done as well as I know I can.	9.1%
I do not feel good. I have not passed many quizzes and am worried about retaking them.	2.3%
I feel bad. I do not think I am learning or going to pass quiz retakes.	0.0%



So far, the quizzes have been...	
Too easy.	0.0%
Fairly easy.	6.8%
Tough, but fair.	86.4%
Unexpectedly hard.	6.8%
Way too difficult.	0.0%



I would describe my effort in the course so far to be...	
Working extremely hard, studying a lot.	34.1%
Working hard in class and doing well on homework, and studying some outside of class.	54.5%
I know I could put more time into studying but I have not yet.	11.4%
I have not studied outside of class and the homework assignments.	0.0%
I am distracted during class and rely on others to help me complete the homework.	0.0%



If/when I have had to earn a token to make up a quiz, the token activity has been...	
Very helpful in helping me learn concepts I did not understand prior to the quiz.	45.5%
Somewhat helpful in solidifying concepts from the quiz.	38.6%
Not very helpful in helping me learn the concepts or understanding why I missed questions on the quiz.	11.4%
Not helpful at all for learning.	4.5%

Figure 4. Combined survey response data for all four classes on agreement scale questions relating to general feeling about the course (**A**), perception of quiz difficulty (**B**), effort in the course (**C**), and utility of token activities (**D**). N = 44 survey respondents out of 65 possible respondents (~68% response rate).

seen.[21] This is a topic we hope to understand more about in a follow-up study.

When asked about changes in the grading of the course, respondents were split on what they would do (Table S13). One response theme was coded as a change in how quizzes were graded, specifically that two questions scored as "progressing" on a quiz count for the equivalent of a correct question. Allowing this change in grading would undercut the idea of not rewarding incorrect answers with partial credit, and has been a common refrain from students in general chemistry courses using this grading system as well.[10] Another theme was coded as a request for changes in mastery-level assignments. Some students felt that the mastery level quizzes and projects were too difficult or not truly optional. Since these assignments were only used to differentiate A-level grades from other grades, the instructors feel that the mastery level assignments should be challenging and it is still a fair part of the grading system. Along those same lines, some students suggested smaller gaps between specifications to earn grades. They vocalized a concern about a bad day during the final exam dooming their grade. While this is a legitimate concern for students, the currency exchange system embedded in the letter grade determinations should help alleviate that worry, and perhaps better explanations of the grading system could help mitigate this concern. A final code related to what students would change about the grading system was a desire for faster or better feedback. This is something that the instructors are considering options for how to address that feedback gap. All told, 20/44 respondents (~45%) said that they would not change anything about how the courses are graded, suggesting that many students had a positive perception of the grading system.

When asked about what changes they would make to the course structure the most common request was to change how the projects were distributed throughout the term (Table S14). Because the project assignments are supposed to be higher on the scale of Bloom's taxonomy, they should take more thought and energy to synthesize material for a presentation or creative project on newly learned material. These responses were concentrated in the inorganic and physical chemistry courses

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where the last half of the semester had students complete two projects (one being mastery level), as opposed to the biochemistry course that had the integrated project more evenly spread throughout the term. Students also requested more opportunities for review before assessments and more time or resources (e.g., conversion factors on equation sheets) on quizzes. Some students did not like the flipped classroom in the biochemistry course, despite it being shown to improve student learning outcomes.[30−32] There were 15/44 respondents (∼34%) that said they would not make any changes to the course structure, or that they found the structure very helpful to their learning (Table S14).

■ INSTRUCTOR COMMENTARY

Overall, the instructors of each upper division class were pleased with the specs grading systems they implemented, and plan to continue using them in the future. Similar to other reports of specs grading systems in chemistry courses, there was more up-front labor to write multiple versions of each quiz, but the grading of assessments was typically quicker, easier, and more frequent than in points-based grading classes with exams.[1] Now that multiple quiz versions have been written and tokens developed, future semesters will ideally have lower burdens on instructor time input, especially compared to traditional grading systems. One other area of increased labor for instructors was administering quizzes outside of class times for students that had reason to miss class periods where quizzes were administered. All the authors of this study had fairly generous policies for students to make up missed quizzes during office hours or other agreed upon times. This did add to instructor workload, but if it became infeasible with larger class sizes then no make-ups could be offered, since students get multiple attempts anyway. The more frequent assessment and grading also led to more productive feedback loops for students to have successful revision attempts, as evidenced by >90% pass rate on weekly quizzes after all attempts were made. This is consistent with the learning gains seen in other upper division courses that have used specs grading.[20,21,23]

Implementing this grading system in multiple courses by multiple instructors across the department was viewed as a benefit for faculty and for students by the authors. Alternative grading systems can be seen as risky, particularly for untenured faculty members, but there is likely to be greater buy-in from students and administration if more than one instructor is driving the change. Although each course has its own unique assignments, all four courses had the same core design: weekly quizzes with multiple attempts, mastery quizzes, and a final project. The instructors believe that having a similar base grading system, even though it is significantly different from the traditional grading systems, minimizes confusion for students who may be enrolled in multiple specs courses at one time. Without much coordination, weekly quizzes tended to be on different days of the week (Mondays for Biochemistry, Wednesdays for Thermodynamics, Tuesdays for Inorganic) so students are not overwhelmed with multiple quizzes on the same day. Although this was not an issue for us, departments who plan to implement specs grading in multiple courses and instructors may want to compare schedules to avoid overlapping of quizzes.

Another positive of having multiple instructors using similar alternative grading systems in the same department is having collaborators nearby to bounce ideas off of, and iterate course designs. For example, through the writing of this manuscript, the inorganic instructor (author M.J. Drummond) realized that having the specs class meet three times a week (as is the case for the biochemistry and physical chemistry courses) was advantageous to the specs structure, and would allow for the movement of the final quiz retake session earlier, and the administering of an oral final exam made possible in the inorganic course. Through the writing of this manuscript, all of the authors have also reflected more on the currency systems and their utility. They do seem to genuinely help student engagement across all specifications, and generally seem to help students earn letter grades that are reflective of their learning and achievement in the course by providing multiple avenues to achieving high letter grades. However, having the currency exchange could also keep students from successfully learning all of the course material and become a prop for boosting grades without promoting learning. At this point, all of the instructors are keeping a currency system in place, but further refining and a narrowing of what counts as currency, or what it can be exchanged for may be changed in the future.

■ FUTURE DIRECTIONS

One remaining challenge is how to best communicate student grade progress before the end of the semester. Some students expressed frustration not knowing their grade at any point during the semester, as they would in a traditionally graded system. This may be an inherent challenge of specs grading, as the multiple opportunities for revision and the currency system allow for the unidirectional movement of letter grades upward at the end of the term. The LMS used at our institution (Blackboard) does not currently have robust support for alternative grading systems, like most other LMSs.[2] The authors have utilized different ways to work around this by customizing grading schemes in the LMS and communicating progress to students via tracking spreadsheets, which is additional labor for the instructor. Contrasting with the student perspective, instructors felt that a positive of the grading system is the flexibility that it allowed for offering students many attempts at revision. In some cases, students needed to attempt quizzes a fourth time in order to earn a passing grade. This was only offered to students at risk of not passing the course, but as opposed to offering an "extra credit" opportunity, a fourth quiz attempt allowed a targeted approach to help struggling students earn passing grades. It does seem that most students recognize that by the end of the semester they have ample opportunity to earn the best grade possible, as evidenced by ∼45% of students saying they would not make any changes to the grading system. We also hope that the use of alternative grading systems in multiple upper division classes and general chemistry will lead to a majority of students that understand and enjoy the mechanics of the grading system, reducing the amount of time that instructors need to explain or justify the system to students. Finally, we are planning a follow-up study that will attempt to better understand the effect of the grading system on student anxiety around assessment. One of the central claims of specs grading is that it should reduce student anxiety,[3] but more studies are needed to prove this claim.

■ CONCLUSION

We report the successful adoption of a specs grading system to four upper division chemistry courses with common specifications between classes including homeworks, weekly and mastery quizzes, and a cumulative or integrated project. Each course had additional specs suited to the purposes of each topic and instructor preference. Student feedback was largely positive and provided some topics for reflection and course revision for the instructors of each course. Future directions include integrating student feedback into our course design and adapting this grading system to lab courses.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.4c00953.

Specification tables, rubrics, implementation notes, and student survey data (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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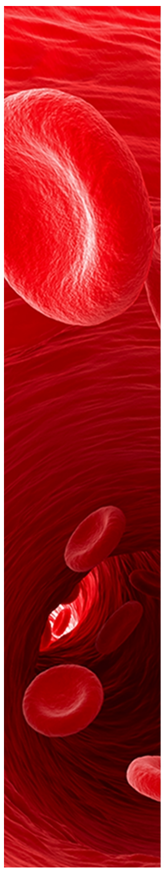

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