Experiences in Developing a Robust Popular Online CS1 Course for the Past 7 Years

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Abstract

Well-run CS1 classes are critical for getting CS majors off to a good start and for serving other non-major students across a university. Universities continue to offer more online courses, to handle more students with limited resources, and provide students more flexibility. Our university introduced an online CS1 course in 2013. The course has improved to the point that student outcomes match our in-person course: Students perform similarly on identical midterm and final exams, and do equally well in the subsequent CS2 course. Student evaluations match as well and are highly positive, consistently rating the course in the top 20% of all courses on campus. This paper highlights how the class has evolved based on experience, into the robust popular course that it is today. Key course features include: Synchronous online video meetings akin to the in-person course, an online chat forum during such meetings that students say increases participation, some active learning during the online meetings, use of modern online learning content instead of a textbook to ensure reading before class, and online auto-graded homework and programming assignments to provide extensive practice and immediate feedback. A key omitted feature is videos; we intentionally have not made use of video lectures in any substantial way. A common theme from students is that they did not originally want to take the course online, but afterwards saying they liked the course better than in-person courses due largely to the surprisingly-extensive live online interaction.

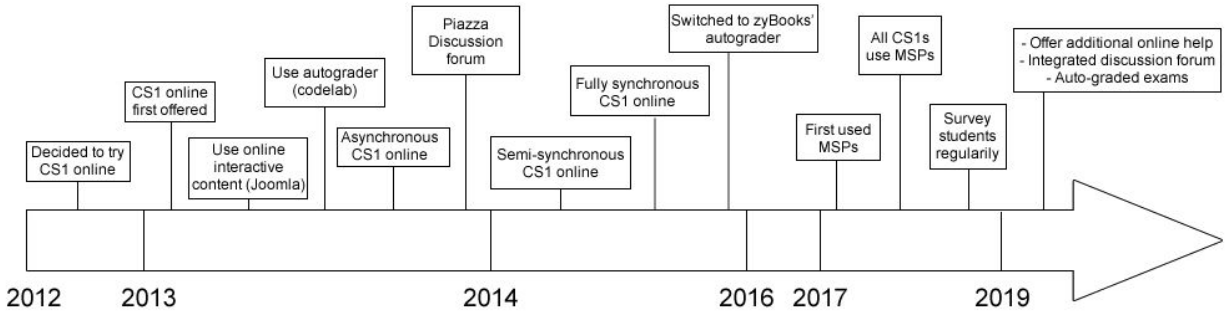
1. Introduction

Our department's CS1 class serves about 1,000 students per year, about half CS/CE majors and half non-majors (engineering, science, math, and more). In 2012, our department decided to try teaching one CS1 section online each quarter. At the time, the decision was not based on a pressing need, but rather a desire to better serve our students. The thought was that an online course would provide students more scheduling flexibility. Another consideration was that our multi-campus university was offering funds for cross-campus enrollments into online courses, and we wanted to consider starting a new revenue stream that would help us improve all our courses. Other considerations included more flexibility for instructors, who could teach online sometimes from home or while on business travel, and an ability to scale classes up or down easily without the constraints imposed by in-person lecture halls and labs. Our department was thus the first to get an online course into the catalog at our 20,000 student public university.

Our initial CS1 offerings were not a disaster, but outcomes were below those of our in-person offerings. Learning outcomes were OK, student evaluations were acceptable, and instructors and TAs were reasonably happy teaching the course. But, we learned a lot, and the course has been extensively refined since those initial offerings. Since the initial offering in 2013, we have taught one section of CS1 online every quarter, with about 70-100 students per quarter, and another 1-2 summer sessions as well with 30-50 students. We have thus offered the course over 20 times, with over 5 different instructors having taught the course in total to well over 1000 students.

The refinements over those years have led to our online and in-person courses now running nearly identically, using the same materials, pace, and exams. Some of the innovations driven by the online course have benefited the in-person course. The online course's outcomes now match the in-person course's outcomes, both in terms of performance and student evaluations. Figure 1 shows an overall timeline of all the "major" changes to our CS1 online course from 2012 when discussions began to current 2019.

Fig. 1. Timeline that highlights "major" changes in our CS1 between 2012 - 2019.



Section 2 shows other styles of online teaching. Section 3 describes the course details. Section 4 discusses the early 2013-2014 years and introduces our CS1 online vision. Section 5 discusses the middle years between 2014 - 2016. Section 6 discusses the most recent changes between 2017. Section 7 concludes.

2. Other styles of online classes

This section briefly details some of the other styles of online classes that are being used. The intention of this work is not to say that these other online structures are "worse" than what we are doing at our university, but rather should be used as a point of comparison for the other options of teaching an online class.

2.1 Massive Online Open Courses (MOOCs)

A MOOC is an online course with the option of free and open registration, a publicly shared curriculum, and open-ended outcomes [1]. MOOCs have been around since the late 2000's and still remain popular today. Universities such as Stanford, Harvard, MIT, Carnegie Mellon, and Yale [2] all offer various courses using this type of online model. MOOCs typically share some of the same characteristics of a face-to-face class; course timelines, weekly topics, assignments etc. MOOCs are attractive since they are usually cheap (mostly free), have no prerequisites to take the course, have no expectations for participation, and are quite flexible. Some MOOCs have affiliations with universities that allow students to formally enroll in the course for credit.

2.2 Personalized asynchronous videos

Another way to run an online course is by having a set of videos for students to watch on their own time when taking a class. Ever since the popularity of online classes started to rise, researchers have spent lots of effort on improving online education. Although using video lectures is not a new concept, Rose [3] showed that even when offering online videos for students to watch, instructors should find a way to make the content personalized. Rose indicated that online courses still required instructor influence for students to be engaged in a class. From this work, various online courses had their instructors create videos for students to watch. Even though these videos covered the 'usual' course topics like providing explanations of course assignments, syllabus requirements, discussing weekly topics, review for exams, and providing answers to student questions, the personalization had a positive impact on students.

2.3 Hybrid learning

Another way to run a class is a hybrid approach of face-to-face class time as well as online class meetups. Through the use of technology, hybrid learning courses allow students to learn new concepts on their own outside of the classroom and then physically come to class to get their questions answered and engage in various discussions [4]. Furthermore, there is additional student engagement as they are able to actually meet with the instructors of the course as well as their peers in the class. Webb et. al. [5] studied the hybrid teaching model and found that students in the hybrid class performed just as well as their peers in a traditional classroom. Webb concluded that hybrid teaching can provide the benefits of both online and face-to-face classes.

3. CS1 course details

Our CS1 course is taught at a public research university that usually ranks among the top 20 public universities by various ranking publications, and often number 1 in terms of social mobility. The university is a Hispanic serving institution, having a majority of students from

minority groups, and with a majority of students being first-generation university attendees and being Pell grant recipients. Our university operates on the quarter system; dividing each academic year into three 10-week quarters: fall, winter, and spring. Additionally, the university offers accelerated 5-week sessions over the summer. During the regular academic year, our CS1 course typically serves around 300-500 students each quarter.

The CS1 online section typically serves 250-300 students per year, for over 1,000 students to date, including CS majors and non-majors, accounting for about 20% of all CS1 students served at our university. The course has been taught by over 5 different instructors, all who use a common curriculum, policies, and exams, and with consistent results.

Our CS1 teaches C++ and covers input/output statements, assignments, branches, loops, functions, and vectors. Each week, the course consists of 3 hours of instructor-led lecture (both in-person and online sections), and 2-3 hours of TA-led labs. The Instructor and Teaching Assistant (TA) each offer 1 hour or more of office hours each week for students to get additional help. A midterm is given in week 6, and a cumulative final is given in week 11. Each exam's points come from half multiple choice questions and half free-response coding questions.

4. 2013 - 2014

4.1 The vision

Our vision for the class involved several key features:

1. **Online interactive content:** We did not want to use a regular textbook, not even an e-book. Textbooks were never a good way to learn programming, and we felt they were even worse for an online course. We decided to create highly-interactive online learning content with immediate feedback, so that learning of the basics could be done by the students on their own.
2. **Automated program grading:** As for any skill, students need extensive practice and rapid feedback to learn. In-person classes were struggling to provide quality feedback quickly enough to feed into a learning cycle. Online classes would need to do better. We thus decided that all homework and programming assignments would be auto-graded with immediate feedback.
3. **Asynchronous class structure**: We originally created the class without any predefined online meeting times so that students could have maximum scheduling flexibility. We instead had optional group meetings, plus instructor and TA office hours held online.
4. **Discussion forum:** We made use of a modern online discussion forum, so students could ask questions, and students/instructors could answer, just as for our in-person classes.

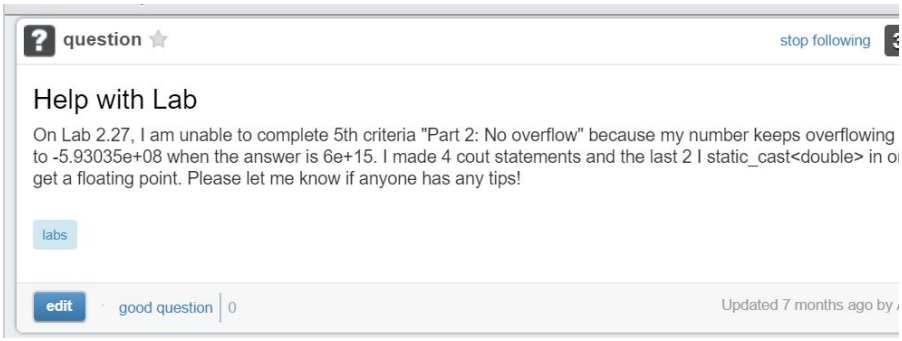
5. **No recorded videos** (almost): Unlike most online classes where the first thought is recording lectures (even short lectures), we were not keen on videos. Students don't enjoy watching video lectures and skip much of them. Videos are also *very difficult to maintain and improve*. Videos seemed like porting the old paradigm (lectures) to the web; akin to playing radio programs on TVs. One instructor did record about a dozen 10-min lectures on key topics, mostly working through examples, and used those for their sections.
6. **Exams**: We gave one midterm and one final exam, half multiple choice and half short coding problems, taken in person at our university or at an approved in-person proctor site. For the online course, we increased the weight of the exams, since we have even less control and knowledge over who is doing the programming assignments. (The in-person class has since increased the exam weight as well).

For online interactive content, in 2012 we created our own content, using HTML, CSS, Javascript, and a content management system called Joomla. That content quickly evolved into a commercial product in 2013 [6] that in 2019 is now in use at hundreds of schools.

We originally used the commercial tool CodeLab [7] for automated homework. We used a homegrown auto-grader for the weekly programming assignments.

We used the Piazza [8] discussion forum, shown in Figure 2, which encouraged more discussion than the forum built into our learning management system. From the start of the class, students were encouraged to post all class-related questions (and personal if needed, directed to the instructors) on the forum. We told students to post any type of question, big or small, or even chunks of their code logic, so that their questions could be answered and also benefit their peers. On average, most questions were answered by another student, the TA, or the instructor within 30-minutes of posting; ensuring that students always felt like they could get answers quickly.

Fig. 2. Screenshot from Piazza online discussion forum.



For the online meetings, we used Adobe Connect [9] (though our campus recently switched us to Zoom [10]).

4.2 What we learned

Students loved the interactive learning content instead of a textbook. They appreciated the automated grading of homework, though didn't like having to access a distinct system from the learning content. They appreciated the automated grading of programs but had many gripes about the system failing at times or marking programs wrong due to output mismatches but without good feedback. We did see that students made good use of Piazza. However, the biggest lesson we learned was that many students did not do well without meetings. Students indicated they had trouble getting motivated to study the content, doing the assignments, and generally keeping up. Our data showed that some students watched the videos, but most did not.

5. 2014 - 2016

5.1 From asynchronous to synchronous

In that first year of 2013, we noted a key difference between the online class and in-person class. The online class had more "disengaged" students, who did very little work and mostly just took the exams -- and did poorly. It was clear that the online structure did not engage many of the young students in our class -- many of whom were first-year students.

We thus somewhat-reluctantly introduced more online meeting times. For a couple quarters, we would start the quarter by providing several weekly meeting choices that students could optionally attend. For another couple quarters, we switched to *requiring* attendance to at least 1 hour of meeting time per week, and then in a later quarter increased that to 2 hours, but attendance was low, and many students had conflicts that did not allow them to attend.

We finally decided to introduce *scheduled online meeting times into the official course definition*, just like an in-person class -- the definition of a "synchronous" online class. We started with one 50-minute meeting per week, plus additional optional meetings and office hours. We found those meeting times to be highly effective in motivating students and keeping them working, but they were too short. In a later quarter, we increased to two 50-minute sessions, and finally increased to match our in-person sections: two 80-minute "lecture" sessions and one 2-hour lab session, each week, with required attendance for the duration of all such sessions.

Such scheduling was in direct conflict with our initial goal of creating an asynchronous class. *We simply decided we initially were wrong.* Students seemed to need the structure and rhythm of regular required meetings, and many of our colleagues at other universities who were experimenting with teaching online courses were saying the same thing. (Others were doing great with asynchronous classes, so we don't claim such synchronicity is a universal requirement

of online classes -- but we found it helped in our case). This makes sense in some ways: People find a live sporting event far more enjoyable than recorded items of the same event, even if not attending the live event in person. There is something to be said for being "part of something that is happening," that is being created right there, with all the associated unpredictability. There is also a sense of "responsibility" that students seem to develop when interacting live with a teacher and a TA.

5.2 Synchronous "lecture"

Our lecture sessions are not lectures at all. We require students to "read" the online interactive content before lecture, so students come to lecture knowing the basics. Thus, during lectures, we instead mostly do examples, like "Let's program a mini-golf scorecard application today." The instructor explains the code as they write it on the fly, and makes many mistakes along the way, some intentionally, most unintentionally. Students really appreciate seeing the instructor make mistakes, as it puts them more at ease about their own mistakes. We call this establishing a "culture of mistakes" and consider it important in any CS1 class, in-person or online.

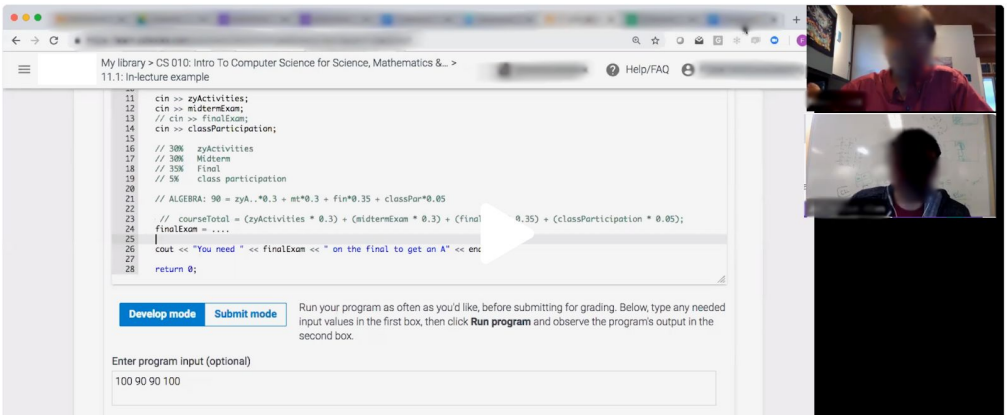
To keep classes interactive, we have students create a google doc at the start of the quarter, and share the link with the instructors. 2-3 times during lecture, students are asked to write some code themselves, typically just 3-5 lines. The instructor randomly opens 5-6 google docs, and discusses the code, pointing out mistakes or improvements. This generally has worked well, with many students saying "pick me!" But some students feel nervous about being put on the spot, and many students don't type and instead just wait to see the answer given afterwards. We give some points for "participating" in this way, but would like to further improve, including using better collaborative coding tools for this purpose. At the end of the lecture, the instructor pastes the example(s) into a central Google doc that students can access, so that they need not focus on copying the instructor's code throughout the session, but rather can focus on understanding the concepts being taught.

5.3 Active TA involvement

Another way we try to keep classes interactive is by involving the TA more in online lectures. During all the synchronous lecture times, the TA would also attend and be on video during the class. Figure 3 shows that both have their video appear. As the instructor is working on examples or teaching, the TA would be active in answering student questions as they come up. This allows students to ask their questions in real-time, and get answers immediately. Since the instructor typically does most of the "lecturing," from time to time the instructor would call on the TA to solve a problem on the spot, teach a small part of the lesson, or to just engage in friendly banter. In addition to all this, the TA would also "show up" to class 10-15 minutes early and stay 10-15 minutes once the class was finished. This allowed the TA to answer further questions from the

class, but more importantly gave the TA time to further engage with the students and build a friendly and professional relationship with the class.

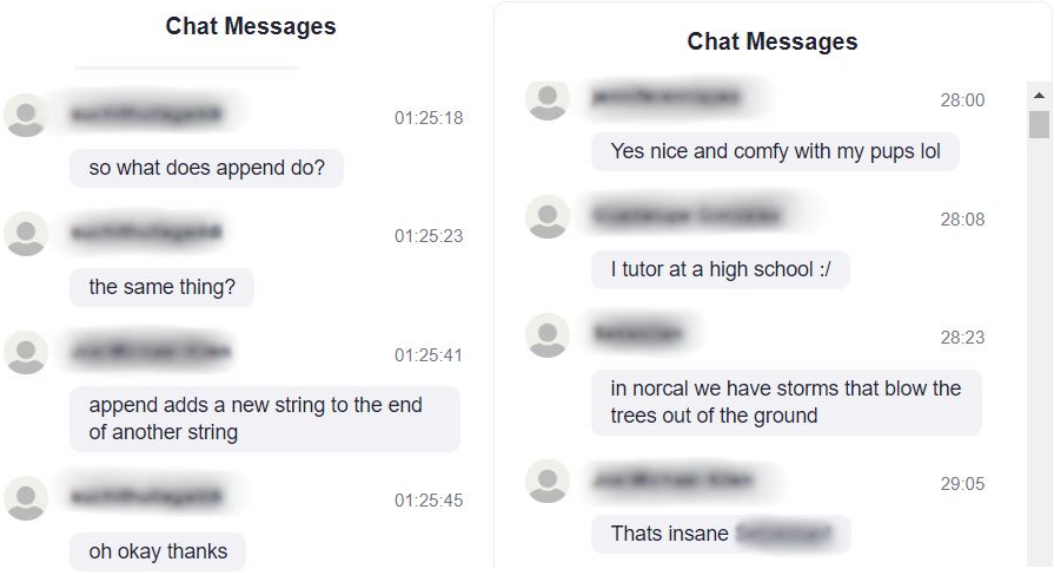
Fig. 3. Screenshot of our CS1 online synchronous "lecture." The instructor and the TA are shown on screen while the instructor codes live examples for the class to learn from.



5.4 Chat

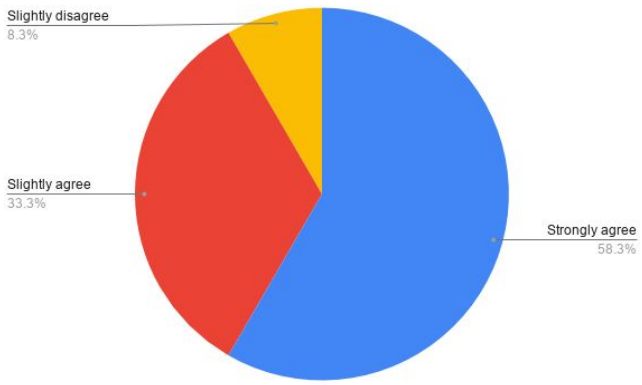
One of the most surprising things we learned was the power of the "Chat" feature that came with our Adobe Connect system. Students immediately took to the chat feature, saying hello to classmates, asking questions about the class and content, commenting on content or the teachers, or just sharing random information like how tired someone was after studying for another class. Figure 4 shows sample conversations happening via the chat module during class.

Fig. 4. Screenshots of the chat box from lecture. (Left) Shows class-related questions being answered. (Right) Shows a fun conversation happening among students.



We found the need to keep the chat focused on the current content being discussed, which has proven simple via friendly cheerful reminders when students get off track, and regularly taking a few minutes in the middle of class to answer any questions related to class structure. In course evaluations, students frequently say that *the chat is what has turned them into liking an online class* even more than an in-person class: It is much easier to ask a question in chat, than to interrupt a lecture by raising a hand and having everyone stare at you. A TA can respond in the chat box, or the instructor sometimes will verbally respond. Even if a student has a personal question, or is still too shy to ask publicly, they also have the option to private message their classmates or the TA to get any question they have answered. Figure 5 shows results from a survey question asked during week 8: "I found the chat box very helpful during lecture." The results show that around 90% of students agree (slightly or strongly) with that statement.

Fig. 5. Results from a week 8 survey question: "I found the chat box very helpful during lecture."



Many instructors indicate that they disable chat because they found chat to be too much of a distraction, with excessive tangential conversations, and even some intellectual bullying. However, we have found that establishing a particular class culture can mostly prevent such issues. On the first day of class, the instructor starts right away showing enthusiasm for the subject, doing examples, asking students questions that they answer in the chat, and enthusiastically answering appropriate questions posted in the chat. This establishes that the norm of the class is a positive, energetic, education-focused place. Research shows that creating such rapport with students is important [11]. Furthermore, we tell students that we will always break midway through class to answer any questions around class structure, which otherwise students tend to ask in the chat at any time, causing distraction. Finally, if students do occasionally get off track, we in a friendly/positive way express appreciation for their enthusiasm but remind them to keep the discussion focused. We also find that having a teaching assistant present in addition to the professor is helpful when possible; the TA not only can answer questions in the chat (by typing), but the dynamic of having two teachers even further helps

students adapt to the culture. Across over 30 offerings, 7 years, 4 instructors, and about 1,500 students, we have had no significant issues with the chat.

5.5 Labs

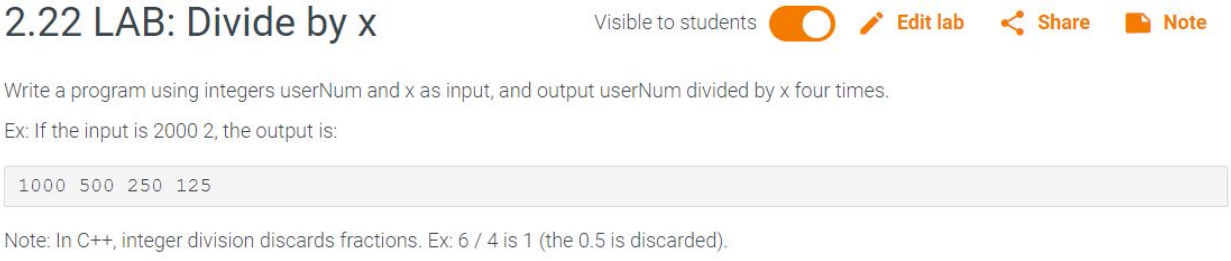
Labs are run by the TA similarly to lecture for the first 20-30 minutes. Then students can work on their weekly programming assignments and use the chat to ask the TA or classmates questions.

Both lecture and lab sessions are recorded, such that students who miss a session can see what was missed, and students can also go back and review.

5.6 Integration

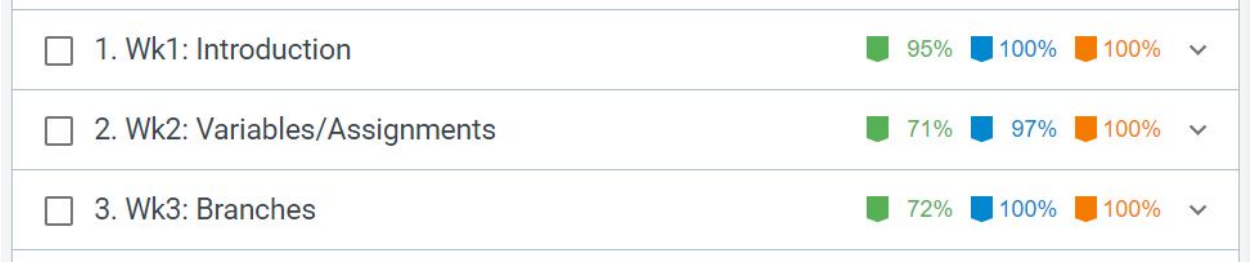
In 2014, we switched from the previous commercial homework system to a new system integrated in the interactive learning content created by zyBooks. Furthermore, in 2016, we switched from our homegrown program auto-grader to an auto-grader integrated into that interactive learning content. Thus, the core aspects of the class -- "reading" (interactive), homework, and programming assignments -- are all together in one system. Figure 6 shows an example programming assignment from week 2 of the class. During week 2, students were learning about variables and mathematical expressions in C++. Each programming assignment has a title, a prompt, and a sample input/output test case for students to better understand the problem.

Fig. 6. Sample programming assignment given to students via the program auto-grader.



In regards to the interactive learning content, we chose to configure material such that each chapter covers one week of the class. This structure allows for students to follow along easily and not get confused when using the online content. Each week students were assigned the same work: weekly readings to be completed before lecture, weekly homework assignments to be completed by Sunday evening, and weekly programming assignments to be completed by the following Tuesday evening (one week after being assigned). Figure 7 shows an example table of contents from the learning content we used. Note, that each week's chapters correspond to the main topic being taught that week.

Fig. 7. Sample TOC showing content covered each week. The percentages indicate the % of the class that finished the readings (orange), homeworks (blue), and programs (green) that week. (The program % is lower because the teacher indicates that 70% program completion yields full credit).



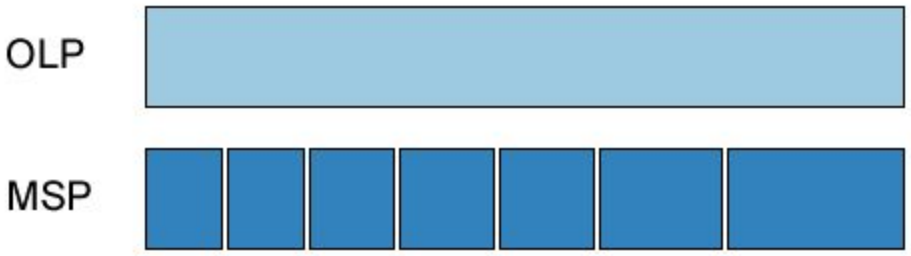
This overall structure for the course worked very well, bringing the online course on par with the in-person course in outcomes, both on the performance on the identical exams, and on the anonymous student evaluations. The online and in-person courses use the identical content and give the same exams; the only difference is that the lectures and labs for the online course are done online.

6. 2017 - 2019

Since 2017, we have had various instructors teach the course, with similarly positive student outcomes each time. And instructors have said they enjoy teaching the class, because of the interactions during meeting times, the flexibility to teach remotely at times, the freedom from almost all grading chores, and the ability to easily experiment with new features.
The online section catalyzes our ability to run experiments. Whereas students in our 3-4 in-person lecture sections can choose to attend any of our dozen or so lab sections, our online students all attend one lecture section and one online lab section. This isolation allows us to easily experiment with certain features in the online section, compared with students in all the other sections. With the class' core largely automated, we now run more experiments each quarter.

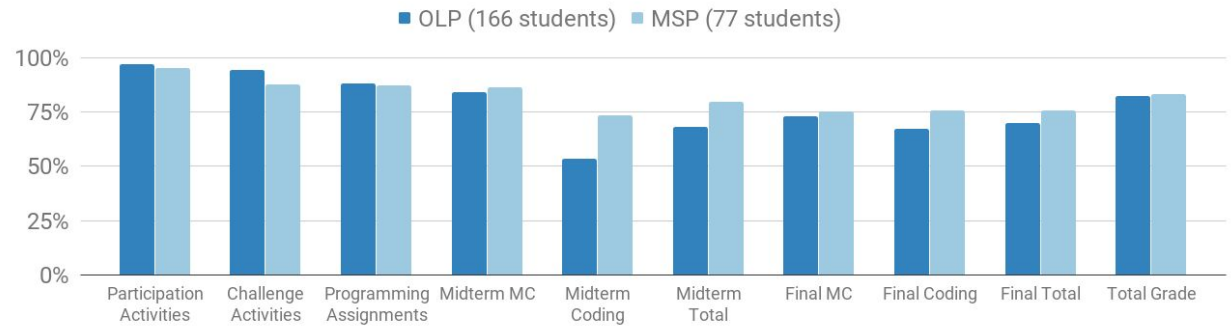
For example, in the Spring of 2017, we ran an experiment in the online section, where we assigned many small programs (MSPs) each week, instead of one large program (OLP). Figure 8 shows a high level comparison between the OLP approach and the MSP approach. With OLPs, students are given one programming assignment to complete as homework each week, whereas with the MSP approach, students are given more, smaller programming assignments to complete each week.

Fig. 8. High level view of OLPs vs. MSPs



The results were outstanding, with exams scores being improved, and students reporting less stress and more satisfaction. Students appreciated being able to switch to another program if stuck, coming back later to work on the program once again. They built confidence completing the easier programs, as well as knowledge that would help with the latter harder programs for that week. Students started their programs earlier each week (as each program looks less intimidating so is easier to start), and they appreciated being able to work on their actual programs during lab sessions. Based on these positive results in the online section, the next quarter all the in-person sections switched to a MSP approach in Fall 2017 and have continued since. Figure 9 shows the grades at the end of the quarter comparing the OLP students to the MSP students.

Fig 9. Spring 2017 student grade results - exam scores improved.



With all students on a computer in the online lecture and lab sessions, in 2017 the online section began giving short surveys at the start of every lecture and lab. In this way, not only could we better understand our students, but we could determine if changes in the class had a positive or negative effect on student attitudes and motivation. This survey methodology provided instructors great insights, and soon instructors wanted similar insights into their in-person sections, so the survey methodology has also been added into the in-person course, which now gives the same surveys at the start of their lab sections (not lecture, as they don't allow computers in the in-person lecture).

We eliminated use of an external IDE, and use the built-in web IDE that comes with the interactive learning content. The students greatly appreciate not having to learn yet another tool (and CS majors will learn an external IDE in CS2).

Looking ahead, we would like greater integration. For example, we'd like a discussion forum directly within the interactive content, and a forum that has a Slack or GroupMe like capability as students seem more drawn to such apps today. We'd like more online help options for students, both automated and human, integrated into the interactive content. We'd like a better way to do collaborative coding during lecture and lab times, again ideally integrated.

Both our in-person and online courses will be focusing on improving our exam methodology going forward, emphasizing auto-generated auto-graded exams, hoping to model the successes at University of Illinois [12], [13] and University of Central Florida [14], [15], [16].

When we first offered CS1 online, the course grades between the in-person offering and the online offering were very different. In Fall 2016, the earliest records we have access to, the in-person course average was 87% compared to the online course average of 77%. Over the past 7 years, as a result of all the changes mentioned, the course grades between the in-person and online CS1 classes have become almost identical. Looking at the total course grades from Fall 2019, the in-person offering got an average of 86% compared to an 83% for the online class.

Furthermore, our anonymous student course evaluations have also steadily improved from 2013 to 2019. On a scale of 1-5, scores have increased as follows each year: 3.7, 3.85, 4.1, 4.2, 4.4, 4.5, 4.5. The 3.7 put the class in the 50th percentile of all classes on campus. During that same period, the physical class started at 4.3 and has increased to 4.5. The 4.5 now puts the class (physical and online) in the 80th percentile, which is somewhat unusual for a large required CS1 class having both majors and non-majors, at a school with a majority of students being minority, first-generation, and Pell grant recipients. Typical student comments in the 2013/2014 online class offerings had the theme of students liking the class but feeling it took a lot of time and sometimes feeling unengaged or wanting more help. The 2018/2019 comments have a few of those but instead are filled mostly with highly positive comments like these:

- "I found this class to be an amazing experience from all of the other classes that I have ever took. The online format makes me less apprehensive to ask questions which is something I appreciate about this course."
- "I thought I wouldn't like the online class but I really enjoyed the class and learned a lot from the first day."
- "I strongly would recommend anyone to take this course online rather than in person! Believe it or not, this was actually my most interactive class even though it was online!"

- "The technique of using many small labs instead of a few large ones was singular in keeping me focused and excited to learn to program. The assignments were organized and grading was instant since it was online. I learned more on coding, and more importantly retained the knowledge, in ten weeks then three semesters at my community college."
- "This is honestly one of the best courses I've had while here."
- "I would 100% take another online course."
- "I was skeptical of an online class at first, but I am very glad I took it now."
- "I don't think I had ever been so excited to actually attend a certain class ever."
- "When I first signed up for this course, I had absolutely no idea that it was online. To my surprise, it was comfy, lay back, and convenient that way."
- "At first I was completely unaware that this was an online class, and after that I was pretty wary. However, after taking the class, I realized that the online format works really well and is as good as or even better than taking an in-person class. I absolutely loved this class."

Note that most students in the online class are NOT self-selecting into an online class. This is due to an unintentional feature of our class enrollment system that makes it non-obvious that the online section is in fact online. In surveys, more than half the class indicated they didn't realize the class was online when they signed up. And of those that realized, many did not want to take an online class but couldn't get into an in-person section due to being full or a conflict.

7. Conclusion

In this paper, we shared our experiences in creating, maintaining, and improving an online CS1 course at our university. What started as an OK course in 2013 has now become one of the most popular and highest rated courses at our university. Over the past 7 years, and after offering at least one CS1 online section every quarter, we have learned a lot about what it takes to make an online course successful. Among key lessons learned were that required synchronous online meetings help keep students engaged and on track, an online chat forum (especially with a TA present) enables a level of student engagement usually not found in in-person classes, and quality online interactive content is highly effective (more so than videos). Readers interested in a short demo video of how we run our online course can refer to [17] (full video [18]). In the past several years, we have assisted several other universities to create new online courses modeled after our course, in some cases simply cloning our entire course for an instructor to step into and teach at their school. We plan to continually investigate and experiment with improvements to the course.

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