On Overcoming the Inherent Challenges in Creating a Revolutionary New Academic Program

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The unique blend of quality education, research, entrepreneurship, and economic development embodied in the operational model of academic institutions in the United States is unparalleled in the world. This unique model has been powered by the intellectual commitment and academic freedom of the faculty. Therein lies the rub for creating new and revolutionary academic programs. In this article, we chronicle the creative solutions we came up with in overcoming the challenges we faced in creating the "Online Masters in Computer Science (OMSCS)" program based on "Massively Open Online Course (MOOC)" technology at Georgia Tech (GT). Our experience may be of value to colleagues embarking on similar endeavors.

1 Supply and Demand for Skilled IT Professionals with a Graduate Degree in CS

In early 2010's we witnessed a significant uptick in the applicant pool for the MS program in Computer Science (CS) at GT- a nation-wide trend due to the need for qualified professionals with advanced skillset to meet the workforce market demand. Half the applicants had academic records worthy of being admitted to the MS program. However, classroom capacity, faculty teaching load, staffing teaching assistants (TAs), and other logistical reasons would limit admittance to less than 20%. How can we scale up the MS enrollment while being cognizant of various challenges?

1.1 Advent of MOOC

Advances in Internet connectivity has leveled access to digital content across the globe [1]. Just as *Business Process Outsourcing* (BPO) took off thanks to the global Internet connectivity, online education, specifically, the concept of *Massively Open Online Courses (MOOC)* took off.

Individual faculty in several premier institutions offered free online courses open to anyone – from introductory to graduate-level courses – in various fields of science and engineering. Faculty recognized both a community service and business opportunity potential in making such courses accessible to a global audience. Coursera and Udacity were first to offer platforms for delivering streaming course content at scale.

Enrollments exceeded 100K globally in popular courses, especially in CS (such as Machine Learning). Yet the single digit percentage completion rate for most courses implied some difficulties [2]. To reduce attrition, the MOOC model needs to reach a target audience both motivated and academically prepared, and provide widely acceptable credentials upon completion.

2 The Vision to Use MOOC to Bridge the Supply-Demand Gap of Skilled IT Professionals

The College of Computing (CoC) at GT saw an opportunity in using the MOOC model for closing the supply-demand gap for skilled professionals. CoC envisioned a quality CS graduate program enrolling thousands of students from the United States and beyond, with minimal disruption to their everyday lives, and at a fraction of the tuition paid to on-campus programs. The partnership of CoC and Udacity, began in 2012, was based on this vision.

Beyond the challenges within the CoC associated with the creation of the program, there were layers of institutional administration that needed convincing of the academic and economic viability of the program [3]. The present article is focused on the pedagogical challenges associated with creating this program.

3 From Vision to Implementation

Vision is one thing; implementation is an entirely different thing especially for revolutionary ideas in an academic setting.

Creating a blueprint for the program, crossing the "t's" and dotting the "i's", while keeping the faculty in the loop is the first hurdle. The second hurdle is proselytizing the benefits of such a program to fellow faculty and convincing them that such a program will help them reduce their workload in the long run if they choose to participate in the program once it is in place. We discuss these challenges and our solution approach in Section 3.1.

While MOOC platforms (such as Coursera and Udacity back in 2012, and EdX soon after) make it possible to disseminate course content worldwide, admitting students at scale, and credentialing and assessing student performance with the same rigor and expectations of on-campus programs requires some serious thought. These challenges and our solutions to overcome the challenges are discussed in Sections 3.2 and 3.3.

Additional challenges include making the program affordable (Section 3.4), contingency plans if the program needs to be closed for any reason (Section 3.5), and timely course production (Section 3.6).

The rest of this section identifies the challenges and the solutions the faculty and the administration of the CoC came up with in a short amount of time (roughly 8 months) to enable a launch of this program in January 2014.

3.1 Challenge I: Faculty Buy-in

Academic programs are created by faculty not by decree of the administration. The first and foremost challenge is anticipating and addressing the justifiable concerns the faculty may have including ensuring that the reputation of the institute is not sullied in any way, and transparency in the expectations of the administration.

The right way to create a successful academic program is to float an idea and let the faculty debate on the pros and cons. In the end, faculty should take ownership of the program to feel a commitment to its successful launch and sustenance in the long run.

3.1.1 Creating an Environment for Free Exchange of Ideas and Concerns

In the Fall of 2012, a committee of faculty was constituted to study the pros and cons. The committee, which by design had no administrators on it, consisted of Tucker Balch, Frank Dellaert, Nick Feamster, Jim Foley, Ayanna Howard, Guy Lebanon, Alex Orso, Kishore Ramachandran (chair), Patrick Traynor, Rich Vuduc, and Bob Waters. The charge to the committee was first and foremost to set the table for free and open exchange of ideas with the entire faculty both for and against undertaking such an academic program. Included in the committee were student representatives to get their perspectives. The committee meetings were open to the faculty to participate if their schedules permitted.

The atmosphere in the committee was almost akin to drawing up an action plan for a technology startup. A SWOT ("strength" "weakness" "opportunities" and "threats") analysis was conducted and presented to the faculty in early fall 2012. Through a series of intense biweekly townhall meetings conducted through the fall, several thorny issues were ironed out ranging from incentivizing faculty for participating in the program, admission requirements, credentialing students, computational requirements, contingency planning for students enrolled in the program, etc. Additionally, we also worried about the demographic mix that would benefit from the program, and how we could increase access to the program for a diverse mix of students. Through the next semester of active planning and engaging the faculty, the official plan was presented to the faculty for vote in March 2013. Since the faculty was engaged in the whole process from the very beginning, a formal vote by the faculty resulted in more than 75% of the faculty voting to approve the program.

We discuss the specific steps that were taken in the proposal to address the challenges relating to faculty buy-in for the program.

3.1.2 Incentivizing Faculty Participation

Academic freedom is the cornerstone of American institutions of higher learning. Indeed, faculty members are entrepreneurs in their own right. They dream up research ideas, seek external funding, make intellectual connections within and across institutions, make curricular advances in their sphere of influence, etc. Consequently, they have different pulls and pressures on their time to meet their own personal aspirations and fulfill their professional commitment to the institutions they serve. Professors at GT are no different.

Therefore, from the very start the committee decided that participation in the new program should be optional. That is, there will be no administration mandated increase in the workload of the faculty. Participation of the faculty in the program both for the creation, delivery, and long-term sustenance was to be entirely on an opt-in basis.

But this also created an interesting dilemma. For the creation of the program, we needed a significant fraction of the faculty to produce the courses to provide a healthy set of options for the students. Now, how do we motivate the faculty to opt-in?

Fortunately, we had some prior experience in this regard. Back in 2007, we won a 4-year contract with the South Korean government to offer an MS program in embedded software (partly streamed from GT

and partly by GT faculty teaching in person at partnering Korea University in Seoul). To incentivize faculty to take part in the program (which was outside their normal workload), we were able to offer "extra compensation" that was beyond their normal academic salary.

The committee devised a similar incentive plan for compensating faculty to develop the video course content for the MOOC-based OMS CS program. The committee pitched it to the faculty that the video production was akin to a "book writing" contract for which the faculty would receive a onetime compensation of $30K for producing the course. Akin to a book writing project, GT being the "publisher" of the video owns the copyright for the video. Every time the course video is used subsequently, the faculty member would receive a "royalty" of $2500 for use of the course video content[1]. The faculty member who developed the course is expected to be instructor on record the first time the course is offered. Subsequent offerings of the course could be by any faculty qualified to teach the material. It is usually the case that the course developer would continue to be the instructor on record in subsequent semesters as well.

A third compensation scheme is for the instructor on record every time the course is offered. The faculty member who runs the course during a semester gets extra compensation of $10K for "administering the course". The courses were to be run asynchronously with the expectation that the students will watch the recorded video lectures. The faculty member who runs the course is responsible for administering the exams, projects, interacting with students on public forums, and assessing their course performance. We deemed this workload to be at most 8 hours a week (roughly equivalent to 1-day a week outside consulting opportunity that is available to any faculty member at GT). It is on this basis that we arrived at the compensation model for running the course.

Through the townhall meeting, the extra compensation idea was socialized with the faculty. It received a positive reception. More importantly, the faculty saw that there was another unplanned pleasant consequence for them in producing the video lectures of their course content. Minimally, it would liberate them from finding substitute help for covering the course material when they were on travel when the same course was offered on campus. More adventurous faculty saw an opportunity to flip the classroom...the scheduled teaching time could be used for enriched discussion by having the students preview the video lectures ahead of time.

3.1.3 Getting the Nod from the Faculty and Upper Administration

In March of 2013, the faculty voted to approve the program.

That was the first step. Next, we had to get the upper levels of the GT administration to approve the program. Every university may have their own internal processes for approval. The specific steps we had to take for approval may not apply exactly to other institutions. Yet, for the sake of completeness we mention our internal process, which may be of value to the readers.

This program was the first in the history of GT wherein all the courses to satisfy a degree requirement were to be offered in distance format. Back in 2007, we had secured the approval of the GT administration for the creation of the joint GT-Korea University MS program in Embedded Software that we alluded to earlier, in which 50% of the courses were taught in distance format. We were able to ride

[1] Even if the faculty member were to leave GT, they would continue to receive the royalty payment every time the course is offered in the program.

on that experience to secure the nod from the upper administration of GT for the creation of the new program. Subsequently, the GT administration took the program to the Board of Regents of the University System of Georgia and secured its approval.

3.2 Challenge II: Creating an Online Education Program at Scale

The aspirational goal of the program was to offer a MOOC-based MS degree *at scale* with the same rigor, rights, and privileges as the on campus Master's program in CS at a fraction of the cost. This aspirational goal raised a number of thorny issues the committee had to iron out.

3.2.1 Admission Criteria

What should be the admission criteria? The committee decided that the goal should be to make the program accessible to knowledge seekers primarily in the United States but inclusively to anyone anywhere in the world so long as they meet acceptable academic standards. The minimum requirement was deemed to be an undergraduate college degree, not necessarily in CS. Beyond that, how do you judge if a student has adequate preparation to be in the program? It became clear that traditional admission criteria such as GRE and letters of reference may not work to implement admissions at scale. The committee came up with a novel admission criterion for the steady state. Let an aspiring student sign up to take two of the MOOC-based courses developed for the program (paying for them). The students (treated like any other student in the program) must do well in them to prove that they belong in the program. If they do so, they get admitted into the program and the courses they took will also count towards their degree.

3.2.2 Credentialing Students and Proctoring Exams

Administering programming assignments and projects for a graduate degree in CS through a learning management system is quite natural since student submissions are done online even for on campus offerings. Exams are a different matter. Potentially students could be enrolled in the program from anywhere in the world. We could not mandate a fixed time for everyone to take the exams. Also, credentialing the students and remote proctoring are important challenges that could threaten the integrity of the program. One possibility is establishing satellite centers where students could take the exams with on-site physical proctoring. Unfortunately, such a solution does not scale and would make the program prohibitively expensive which is at odds with the high-level goal we set for ourselves. Fortunately, thanks to advances in computer vision, camera-based remote proctoring obviating the need for manual vigilance of the camera streams was gaining traction and startups were offering such services [4] and we could work out the details of administering remote exam at scale using such a platform. The specific platform which we decided to use for this purpose, proctortrack [4][2], allowed the creation of the exams, timed-test taking, and video-based proctoring of the exams to ensure the integrity of the test taking. We will elaborate on how this platform meets our needs in Section 4.

3.2.3 Flexibility for Knowledge Seekers

The expectation is that this program would be attractive to knowledge seekers who are at a different stage in their lives. Specifically, the program would appeal to students who are already in the workforce and see this as an opportunity to enhance their skillset without a major disruption in their lives. Life happens. Students may stop and start in the program and may take longer to finish the degree requirements juggling their day job and the course work. We built in flexibility for students to drop a

[2] Recently we have switched to a different proctoring system called Honorlock for administrative reasons.

course without affecting their GPA, and/or withdraw from all courses in a semester without any repercussion on their transcripts.

3.3 Challenge III: Aligning the Online and On-campus Offerings

One of the guiding principles in developing the program was ensuring that the online program would have the same rigor and expectations as on campus courses. In this sense, except for the delivery format, the learning outcomes for every course had to be the same as its on-campus counterpart.

3.3.1 Maintaining Rigor and Meeting Expectations

Students who sign up for the program could come from varied backgrounds. They may not even have an undergraduate degree in CS. How do we ensure that they can succeed in the program? This is precisely the reason for the admission criterion we used which was based not on their background but on their ability to do well in a couple of foundational courses before they are admitted formally into the program. It served as a sieve for a knowledge-seeker to self-assess their preparedness for succeeding in the program.

To put this challenge in the proper perspective, a misalignment of course expectations and student preparedness happens in the on-campus graduate programs as well. The usual remedy is to direct the students to either audit or take an undergraduate course as remedial work to get prepared for the graduate course. Unfortunately, this mechanism is not available for the online students since the undergraduate courses are not available for them in online format. Instead, for every graduate course we fully disclose the assumed knowledge units and skillsets (in terms of programming, mathematical, and other proficiencies) so that there are no surprises for a student taking a graduate course. We point to online resources (e.g., both at GT, and publicly available MOOC courses) that the students may be able to use to equip themselves to prepare for any given graduate course. We also have been creating and offering introductory courses to aid potential students acquire the needed background. For example, we already have created an introductory operating systems course to prepare the students for the more rigorous graduate level operating systems course; and three undergraduate programming courses.

A natural question that arises is the disparity in the educational experience of online students compared to on-campus students. On-campus students do have the advantage of in-person interaction with the faculty. However, it is a fact that with class sizes of over 75, the interaction potential diminishes rapidly beyond the first few rows of the classroom. In fact, on many campuses, in popular entry-level courses (e.g., machine learning), it is not uncommon for students to be seated in overflow areas watching the lecture on overhead screens since the class size (> 100) far exceeds the classroom capacity. Of course, students on campus have the opportunity to visit the professors during office hours and establish a rapport which is not possible for the online students. Nevertheless, enterprising online students find a way to establish a personal relationship with professors as evidenced by the fact that many online students follow a course that they like with independent study with the professors. On the other side, it is also worth mentioning that only a small fraction of on-campus students establishes personal rapport with the faculty.

3.3.2 Computational Resources for Programming Projects

One would be tempted to think that provisioning computational resources globally to carry out the CS projects in the courses should not pose any serious challenges thanks to Cloud technology. As an aside,

even for on-campus courses there is a trend towards relying on the Cloud for meeting the computational needs. However, some courses may have specialized needs. For example, there may be a need to access the bare metal for accurate timing measurements in some programming projects which would not be possible due to the virtualized nature of the Cloud resources. There is no easy solution to this problem since it is not feasible to provide access to bare metal at scale locally in any academic institution. Faculty may have to come up with creative approaches to circumvent such issues while still providing the expected learning experience. As an example, in the advanced operating systems course, the students are expected to implement and perform comparative timing measurements of different synchronization algorithms on parallel machines. The solution was to use the Cloud resources for the students to implement and validate the functional correctness of their algorithms. The instructor provides students with comparative timing measurements of the algorithms on a real parallel machine (implemented by the teaching team), and the students are asked to explain the results.

More generally, moving programming assignments to the Cloud requires some initial investment of time for the faculty and the teaching assistants, as well as a learning curve to surmount to adapt to the Cloud. Besides, there are multiple Cloud providers and there may be preference for one over the other for each individual faculty. Each institution has a different approach to this issue, but it is now bubbling up at the national level as evidenced by the recent roundtable discussion organized by the CRA [5].

3.3.3 Calendar Alignment

It is also conceivable that a faculty member would be concurrently teaching the two versions of the course during the same semester. Cross fertilization of student experience across these two simultaneous offerings is another enabler to maintain the rigor and expectations. From this perspective, and from the point of academic logistics, we decided that the online courses (start and end) would be aligned with the semester schedule of GT. Further, such an alignment with the campus calendar would make it easier for faculty to plan their lives for both the students and the teaching team (both faculty and TAs).

3.3.4 Transfer Credits

Evaluating courses taken elsewhere for transfer of credits is not new for any academic program. In the normal scheme of things, a faculty member with domain expertise would be requested to weigh in on such matters. However, the expected scale of the program could swamp the system if it is not clearly laid out right at the outset. The concern was ensuring that faculty do not get over-burdened with such requests. The solution was to increase the professional technical staff in the administration to deal with the potential increase in this load in a manner that is consistent with the practice already in place for dealing with such requests resulting in minimal addition burden on the faculty.

3.3.5 Moving Between Online and On-campus

Knowledge seekers come in all flavors. Even for those who join an on-campus program, some may not be able to continue the pursuit of the program for a variety of reasons – economic conditions, family situations, etc. By the same token, a student who signs up for the online program may want to move on campus perhaps just to experience campus life. The committee took it upon itself to clearly identify such non-standard pathways for maximum flexibility while adhering to realities such as classroom capacities on campus. The process for switching is quite simple. A student in the online program fills out an online form desiring to switch campuses well in advance of the semester start date and apprises their academic advisor. The approval usually takes a couple of months, and takes into consideration some

logistical parameters (e.g., impact on on-campus class sizes, academic progress of the applicant, etc.). It is uncommon to have requests turned down but does happen. The movement in the other direction is similar. To date, the traffic in either direction has been minimal. Between Summer 2018 to Fall 2021, around 150 students have moved from OMS to on-campus; and around 40 have moved from on-campus to OMS.

3.4 Challenge IV: Creating an Affordable Yet Self-sustaining Online Program

We wished to create an affordable higher education program at scale using MOOC technology at a fraction of the cost of quality on campus programs. We knew we could do it in the steady state. But how do we finance it in the short run? Being a public university, GT has fiscal constraints. In parallel with the deliberations of the faculty committee to iron out the details, the College administration worked to create the financial base for bootstrapping the program. Specifically, AT&T came on board to provide a generous initial gift of $2M to produce the courses and the launch of the program pending approval by the faculty. Our estimates were that we needed to scale up to 1000 students in the program to break even at an affordable tuition of under $7000 per student to complete the degree requirements. We were optimistic that we will get there in a couple of years, but we wanted to start small initially to make sure there are no rookie mistakes. AT&T followed the initial gift with an additional $2M gift during the ramp-up period until the revenue from the program could start covering the costs.

This begs the question, could GT have pulled this off without the timely gift from AT&T? The answer is a qualified yes. Producing each course is like a mini movie production and the initial estimate of the cost of producing each course with Udacity was $300K, which included the one-time compensation of $30K for the faculty. Depending entirely on GT to finance this effort, while within the realm of possibilities, would at best have been a slow start. Besides, it could have also given a stronger voice to the naysayers in the faculty. Also, it may have been much harder to justify the significant cost reduction for a student in the OMS program compared to the on-campus program.

The key to fund-raising for such an effort is to pitch it as a win-win for all partners. AT&T found the program as a way of offering an opportunity to its own workforce to elevate their skillset if their employees could qualify to get into the program, and it would serve as an indirect retention tool for the company. Udacity had a share in the revenue: initially it was 40%, later it became 35%, and now it is 0% since the program is entirely run from within GT.

To date, we have over 50 courses now produced and offered in the program. The cost for production has come down to $100K since it is now done internally using the resources of GT's professional education unit instead of through Udacity.

The revenue from the program in AY 20 is $13M. The revenue sharing is three-ways: GT-central – 55%; CoC – 35%, and GT professional education – 10%.

3.5 Challenge V: Exit Strategy

A three-way partnership between GT, AT&T, and Udacity was at the core of the program being envisioned. The program would help transform the lives of knowledge seekers who either could not afford the high-cost of graduate-level higher education and/or afford the disruption in their lives to enter a full-time on-campus program. At the same time, we had a responsibility to ensure that there would be pathways for students who come on board to finish the program if for any reason GT could not

continue to offer the MOOC-based program. There have been several instances of academic programs started by western institutions in other countries that folded for a sundry of reasons. Therefore, the committee also worked out the details of exit strategy while ensuring that the students already in the program were not left in the lurch. Succinctly put the exit strategy was a commitment to the current enrollees in the program that they will be able to complete their degree requirements if in case the program offering is scrapped for whatever reason.

3.6 Challenge VI: Pipelining Course Production

Once the approvals were in place, the real work started. We had committed ourselves to launch the program in January 2014. So, we had just about 8 months to get a set of courses ready for the launch. This aggressive timeline would have been impossible to meet were we to wait for all the courses needed for students to graduate to be produced before the launch date. Apart from faculty availability, an important bottleneck was the limited recording facility to do the video production in a short amount of time.

The approach we took was to pipeline course production. A small coterie of faculty became pioneers in signing up for creating the video content for the first set of five courses that were used to launch the program in January 2014. Nick Feamster (networking), Charles Isbell & Michael Littman (machine learning), Alex Orso (software engineering), Sebastian Thrun (Robotics), and Kishore Ramachandran (advanced operating system) were the pioneers. In parallel, we got commitments from additional faculty who opted-in to produce courses so that we can keep the course production pipeline busy to have the courses ready for the subsequent semesters. This plan worked out really well.

Udacity was the MOOC platform used for course production. Udacity had a unique pedagogical style for giving the learner the feel of an instructor talking one-on-one with the student, sort of like sitting at a bar and sketching out ideas on a napkin to a friend! What this meant was video production of a course was NOT just using an existing powerpoint deck of slides and recording a talking head going over the videos. It really called for a rethink as to how one was going to make the learner's experience "personal" despite being virtual. This style meant writing the presentation content using one's own handwriting. Since the attention time of a learner is typically less than 10 minutes, one had to spend some time thinking about breaking up an hour-long video into roughly 6 to 10 segments. Also, to break the monotony and to help in assimilating the content, one had to think about quizzes that could be incorporated in between video segments.

Every course was assigned a course developer by Udacity. Though the course developer would be conversant with the technical content of the course, their primary role was to help the course owner develop the course material consistent with Udacity's pedagogical style. The time commitment to produce the course was non-trivial. For e.g., to produce a one hour of video recording it took on an average 8 hours of work (including the actual recording time). The pioneers who signed up to create the first set of courses for launch would tell you that they grossly under-estimated the amount of effort that video production of the course material entailed. The initial experience of the pioneers helped streamline subsequent course production in later semesters. For e.g., personalized fonts matching the writing style of each course owner was developed so that they could type the content rather than having to handwrite them as the pioneers did for the first set of courses!

4 How Does a Typical Course Run in the OMSCS Program?

As an exemplar of how a course is run, let us review CS 6210, an advanced operating systems course taught by the first author. The content of the course is entirely drawn from a set of seminal papers. Apart from the fact that there are no live lectures, the expectations of the students in terms of the assessment units that determine their performance in the course are the same as in the on campus offering of the same course. The students are given a week-by-week schedule of lectures they should watch. There is a weekly one-hour live video hangout wherein the professor engages with the students. The purpose of the hangout is to review the material that the students should have learned from watching the previous week's videos[3], and answer student questions. The students have forums for discussion of the course material, projects, homeworks, and exams. The video hangout helps to address some of the lingering questions in the online forums through direct live interaction of the professor with the students. Since students may be from different parts of the world, not all of them may be able to tune in to the live hangouts. The hangouts are recorded and made available for all the students. This course has four hefty programming projects. The projects are made available to the students using a learning management system (LMS)[4], and the students turn in their projects using the LMS. In addition to the weekly hangout with the professor, the TAs assigned to the course hold office hours to answer student questions regarding the programming projects. Timed tests are conducted using proctortrack. A student taking the test must have a webcam on their computer. Proctortrack takes over control of the computer for the duration of the test. The student starts by showing their id for credentialing. Further, they show the surrounding area where they are taking the test. The only action that the student should perform for the duration of the test is type the answers to the questions displayed on their screen by proctortrack (of course navigating the test back and forth during the session). Proctortrack records the video and audio tracks of the student taking the test. Its postmortem analysis flags places in the video that an instructor/TA may have to check for any potential infractions. From our experience, the number of severe warnings is quite small. For example, in a 120-minute test taken by 100 students, we would typically observe cumulatively for the entire class less than 10 severe warnings (e.g., student switching tabs during the test, opening another window, etc.). Most of these warnings usually turn out to be benign and quickly resolved by the TAs. The number of false positives and false negatives generated by the system is also quite small. Anecdotally, some students have privacy concerns as to how the collected data during proctoring may be used. We assuage student anxiety to some extent via the clearly stated policies of the proctoring company we use. Nevertheless, some students take steps on their own to minimize risk, e.g., using a non-personal laptop to take the test, and uninstalling the proctoring software after the test.

Using this course as a sample, it is interesting to compare the performance of the students who were in the on-campus and online version of the same course in Fall 2020. It should be re-iterated that the course content and the graded items are the same for both the offerings.

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[3] Not unlike the way courses are taught in an on-campus setting, it is the responsibility of the course owner to periodically update the content, i.e., the recorded videos. Machinery exists in the system to enable such periodic updates. To date, there have been mostly course-owner driven updates with the exception of complete re-do in two courses where the course ownership changed.

[4] Canvas is the LMS that is currently used for the OMSCS program.

Table 1: Comparison of an exemplar course offered on-campus and online

Program	Total enrollment	A's	B's	C's	D's	F's
On campus	57	40 (70%)	10 (18%)	3 (5%)	3 (5%)	1 (2%)
Online	160	130 (81%)	19 (12%)	6 (4%)	1 (1%)	4 (2%)

In Fall 2020, due to COVID-19, the "on campus" offering was also online! The only difference is that the on-campus students had the advantage of live synchronous streaming of the lectures. Table 1 shows the distribution of grades for the two offerings. Pre-pandemic, the on-campus offering resulted in a higher percentage of A's (e.g., 77% in Fall 2018). Though it is just a sample, it perhaps goes to show that online students were more prepared for remote learning than the on-campus students during the pandemic.

We used a separate public forum (Piazza) for each of the online and on-campus offerings of the course. The instructions to both set of students was exactly the same. Use the public forum for discussing any conceptual or project related questions, and collaborative peer-learning. In general, the online students tend to be more sharing and collaborative perhaps due to demographics (median age of OMS students tend to be around 30) and the fact that public forum is the only vehicle available to them for interacting with their fellow students.

5 A Lookback at the Program Since its Launch

We announced the launch of the program in the summer of 2013 to invite applicants to the program. OMSCS was launched in the Spring of 2014 with an initial enrollment of 380 students. Even though MOOC courses got their name due to the possibility of educating vast number of learners at once, we intentionally kept the numbers small initially for all the right reasons (logistics of admission, credentialing, size of teaching teams, testing the mechanisms we put in place for ensuring the integrity of the program, etc.). Our intent was to start slow, fix any kinks in the system, and ramp up in the subsequent semesters. The launch garnered considerable media attention due to its revolutionary nature for offering higher education at a fraction of the cost of on campus education; plus, its subliminal goal of making it possible for knowledge seekers to retool themselves without having to uproot their lives. We had butterflies in our stomachs after the launch since so many things could potentially go wrong to sully our reputation. But thanks to the untiring efforts of the faculty to dot the "i's" and cross the "t's" before the launch, there were only tiny hiccups. Such hiccups included not knowing the scalability of some public utility software for document sharing which were used for team formation in group projects. We were pleasantly surprised that there were no catastrophic events to torpedo the program. Still the first few semesters were tense despite the support we received from our peers nationally and internationally for launching such a bold new program.

In December 2015 (after just 6 semesters including the summers since launch), we had the first commencement for the OMSCS program. We were astonished to see about 18 students, most of them with full time jobs and families, had completed the requirements of the program in such a short time despite the pulls and pressures that they all had in their respective lives. It was such an emotional scene to see this first batch of graduates who could not have even dreamed of acquiring a higher education due to their respective circumstances but for the OMSCS program.

As of this writing, the official enrollment figure has grown to 11,085 in Spring 2021; and 4,640 students have graduated (not including Spring 21 graduates) from the OMSCS program.

Table 2 gives the demographic breakdown of the student enrollment in the program. The demographic shift is interesting to note. In the first intake of students in 2014, 66% of the 380 students were White Caucasian; 23% Asian; and 11% were non-white (Black, Hispanic, etc.). In Spring 2021, with an enrollment of 11,085, White Caucasian account for only 37%; 50% Asian; and 13% non-white. It is a welcome trend to see that the number of women enrolled in the program has grown from 9% initially to 20% in Spring 2021. For comparison, in Spring 2021, the number of women enrolled in the on-campus MS program in CS at GT is 24%. The higher percentage of women in the on-campus program could be attributed to the fact that most of them international primarily from India, China, and South Korea. On the other hand, most of the women in the online program are domestic students. It is well-known that participation of women in STEM programs, especially in CS, is a major problem in the U.S., and there are concerted efforts (e.g., broadening participation in computing by the National Science Foundation) to address this problem. The international enrollment in the program has gone up from 15% initially to 45% in Spring 2021.

Table 3 gives the demographic information for the students who have graduated from the program to date. The cumulative number for women graduates has grown to 15% from a very small number in the first batch. The cumulative number for Non-White graduates is at 12% (excluding international students), which would be mostly comprised of ethnic minorities (Blacks and Hispanics). This number is not that different for the on-campus graduate program in CS at GT or elsewhere in the U.S.

Table 2: Demographics of OMS Enrollment

Year	Number of Students	Median Age	Demographics				Demographics		
			Women	Men	US	Intern'l	White	Non-White	Asian
Spring 2014	380	33	9%	91%	85%	15%	66%	11%	23%
Spring 2021	11085	29	20%	80%	55%	45%	36%	14%	50%
Cumulative (2014-21)	23839	28	18%	82%	68%	32%	40%	15%	45%

Table 3: Demographics of OMS graduates

Year	Number of Students	Demographics				Demographics		
		Women	Men	US	Intern'l	White	Non-white	Asian
Fall 2015 (First batch)	18	Less than 5	More than 13	65%	35%	45%	0%	55%
Cumulative (Up to Spring 2021)	4,640[5]	15%	85%	70%	30%	47%	12%	41%

[5] In the just concluded Spring 2021 semester, an additional 673 students have graduated. We will include the demographic data including these new graduates in the final version of the paper.

5.1 Prospects after OMSCS Degree

The diploma awarded to an OMSCS graduate is the same as that for on-campus graduates. Therefore, from an employer's point of view they cannot distinguish between on-campus and online graduates. A survey of the OMSCS graduates conducted in Spring 2021 (351 students participated) revealed some interesting statistics:

- 96% said it was worth the investment
- 95% said would recommend it to others
- 81% said it helped their careers
- 48% said it helped them secure a higher salary
- 36% have joined a new workplace since completing OMSCS
- 25% have been promoted since completing OMSCS
- 6% have started teaching CS at either the high school or college level
- 5% have transitioned into the tech sector from outside of it

5.1.1 Unplanned Consequences

One of the most significant unplanned consequence is the boost in self-esteem and confidence that the OMSCS program has provided to the students, which are mostly anecdotal evidence gathered from personal stories at commencement and/or public forums (such as reddit). For e.g., so many students say they never dreamed that they will ever be able to get an advanced degree from an institution of higher learning such as GT. Some openly admit that given their credentials they did not think that they even had a chance to enter the program at the time they applied for admission. Because of our admission criterion basing on what they can do *now* as opposed to that they did not accomplish in the *past* is such a shot in the arm for bolstering their confidence and self-esteem. To be absolutely honest, pragmatics decided our admission criterion but it is so heartening to see this unplanned consequence of our decision.

A second unplanned consequence is the mentoring that the OMSCS alums and seniors give freely and caringly to the new entrants. This service lifts a huge advising and counseling burden on the OMSCS workforce allowing them to focus on ways to improve the program and scale up to larger numbers.

A third unplanned consequence is the eagerness of the OMSCS alums and seniors to "give back" to the program. Many signup willingly to be TAs for the courses they enjoyed sometimes even without any compensation. For the scale of the program that exists currently and expected to grow to, it would well-nigh be impossible to offer the courses depending purely on on-campus TA help.

5.2 Impact on On-campus MS Program

There were some well-grounded faculty trepidations that OMSCS could put a big dent in the on-campus MS program. Fortunately, this did not happen for a few of reasons. For one, on campus program offered opportunities for personal interaction for students with faculty. This opportunity was crucial for placement of students in internships and such; entry level graduate students (especially from abroad) recognized this value proposition. Further, the OMSCS program vastly increased the pool of TAs needed which meant that most MS students got financial support. Lastly, a significant fraction of the entry level graduate students wanted to test their own passion for doctoral studies by first enrolling in the on-

campus MS program. In addition, many international students take the on-campus program so they can get an entry visa to the US. It is interesting that for these reasons, the on-campus enrollment has held steady (and not grown significantly mostly due to our capacity limits).

5.3 OMS CS Program Logistics

Typically, OMS students sign up for 1 or 2 courses every semester. The average is 1.3 courses per student. Enrollment attrition does happen in individual courses every semester. There could be several reasons, the most likely one being that the student does not have the right background for the course. Additional reasons include family and work circumstances. An interesting evolution in this regard is how much new entrants to the program listen to the advice of their seniors! The advanced operating systems course that the first author of this article teaches is a case in point. Despite abundant information available to the students on the required background to sign up for this course, the attrition rate used to be as high as 50% in the first couple of years of launching the program. However, this number has settled down now to a more predictable 10%-20% range in recent times (which is not very different from the on-campus enrollment attrition seen for the same course). The primary reason is the wisdom imparted by those who successfully completed the course to the aspiring new students. Note that a student who drops a course in one semester often comes back to take the same course the next semester. The average attrition rate per course for the entire program is around 6%.

Admission into the OMSCS program was trickier than we had originally envisioned. The original technique of allowing students to take two foundational graduate courses as non-degree seeking students to prove they belonged in the OMSCS program seemed like a good strategy initially. However, as we scaled up, this technique proved logistically more daunting. We have kept the spirit of the original technique but modified the process slightly. Now ALL students who meet the minimum criteria for admission[6] are admitted "conditionally". Within the first year, they must complete the two foundational graduate courses and get B or better in them to be accepted into the program formally.

The retention rate for the program from its inception is 65%, i.e., this is the percentage of students who have either graduated or are still in the program. The 35% who do not make it to the finish line includes those that did not meet the admission requirement of successfully completing two foundational courses to prove that they can succeed in the program.

Overall, attrition in the program happens for one of three reasons: (a) The student fails to meet the admission requirement to move from a conditional accept to a full accept. (b) The student under-estimated the rigor and commitment expected for succeeding in the program. (c) The student is just a knowledge seeker wanting to hone their skills in some specialty area (e.g., machine learning), and acquiring a degree is not an end goal.

A small number of students get the "PhD bug"; to date, over 50 OMSCS students have entered the CS PhD program, some at GT and others elsewhere.

5.3.1 TA Support, Counseling, and Transfer Credits

Finding adequate TA support for the courses is a challenge. We need roughly 400 TAs every semester. There are four pools of students we draw from to meet this demand, namely, alums of the OMS program, current students in the OMS program, on-campus MS, and on-campus PhD students. For e.g.,

[6] http://omscs.gatech.edu/program-info/admission-criteria

in Spring 21, we had the following distribution of TAs: OMSCS alums – 165 (43%); current OMSCS students – 102 (26%); on-campus MS students – 69 (18%); and on-campus PhD students – 50 (13%).

On campus courses typically are staffed with a student to TA ratio of 30:1. Project intensive advanced courses with moderate enrollments (less than 200) tend to have a ratio close to the on-campus courses. For large enrollment OMS courses (e.g., machine learning with enrollment > 1000), we use a 50:1 ratio. The TAs are arranged hierarchically to ensure that there is equitable division of labor and everyone is doing their fair share.

We have professional staff as part of the operation of the OMS program who help with the logistics of academic counseling and transfer credit requests. This organizational structure ensures that the faculty do not see any workload increase beyond what they voluntarily sign up for to teach in the program for extra compensation.

6 Implications of the Program for the Future of Higher Education

We are in the middle of dealing with COVID-19. In Spring 2020, academic institutions across the entire world were scrambling to figure out how to continue with the academic programs without physical presence on campus. Faculty who had been teaching OMSCS courses were a great resource to fellow faculty both within GT and beyond in helping with ideas for transitioning to the remote learning format.

Most if not all OMSCS courses publish a schedule of video lectures that the students are expected to watch and assimilate on a weekly basis, discussing amongst themselves using online forums such as Piazza. A lot more peer learning happens with the OMSCS format than what we have observed with on-campus courses. Besides, many students bring a lot of "street knowledge" owing to their years of professional experience, which is often valuable even for the teaching team! Most if not all instructors have weekly "video hangout" for their courses, which gives face time opportunity for students with the instructors. Watching the videos the previous week prepares the students to ask insightful clarifying questions during the hangouts. *Flipping the classroom* for on-campus classes has not always met with as much success as one might expect due to the many pulls on the time for on-campus students. Due to the nature of the program, OMSCS program offers greater opportunity for the success of the flipped classroom model, and recognition by the students that this is the only opportunity that they have for live interaction with the faculty. Of course, due to the geo-distribution of the students in the program not all students may be able to attend the hangouts. Yet, posting questions ahead of time by the students and posting the recording of the hangouts for those who missed it, the space-time issues can be mitigated.

The OMSCS experience and the need to deal with remote instruction for even on campus courses due to COVID-19 have given us food for thought on the pedagogy of higher education. Educators all around are discovering novel and interesting ways to impart learning. Even when life returns to normal after COVID-19, there certainly will be changes in the way we teach students. One concrete example, is a technique for facilitating peer learning. To reduce student anxiety in taking timed tests online, the first author of this article invented a new method. The test questions are released to the entire class well ahead of time allowing students to discuss the questions and solutions thereof using messaging forums. Each student has to take a "timed closed everything test" at a time that suits their schedule (within a test-taking window spanning two days). The test is proctored using the same online proctoring system

we use for the online students. From the feedback received from the students, this technique has greatly reduced stress in pandemic time, and the intent is to continue the technique even though Georgia Tech has returned to in-person lecturing for on-campus offering as of Fall 2021.

7 Conclusions

OMSCS is a new way to provide a MOOC-based quality CS graduate program at scale, at a fraction of the cost of on-campus education. It is the fruit of a coordinated effort by the faculty and administration of CoC at GT, plus creative partnership with industry. OMSCS, now reaching over 11,000 students, may face technological challenges on scaling up to even larger class sizes: student performance assessment cannot be entirely automated, streaming platforms may reach their scalability limits, and enlisting TAs as class size increases would become more challenging. GT CoC has been a pioneer in providing a high-quality low-cost MOOC-based graduate program in CS, yet there is a wide scope for growth as demand for skilled CS workforce far exceeds the growth capacity of the OMSCS program. Since OMSCS' initiation over thirty institutions have established over 70 similar highly affordable MOOC-based online programs [6]. We anticipate that many other institutions of higher learning will follow suit.

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