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Teaching Software Quality Assurance (SQA) During COVID-19 Using the HyFlex Approach – Course Design, Results, and Experiences

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Abstract

This full paper discusses the HyFlex pedagogical approach to teaching a highly interactive face-to-face Software Quality Assurance (SQA) course during the COVID-19 pandemic. HyFlex, short for hybrid-flexibility, is a teaching model where instructors and students have the option to attend scheduled courses face-to-face (F2F) or remotely. In this teaching model the learning outcomes for the course remain the same for all who enroll regardless of the mode of attendance.

Our HyFlex SQA approach consists of lectures (in class, with video recordings), face-to-face activities, as well as group assignments, group projects, and exams all facilitated through an online campus management system. During the lecture period, the instructor delivers content in the form of lecture slides and writing on a whiteboard. This poses significant challenges for the instructor, as the learning outcomes have to be delivered in different modalities, but with the same quality. This is particularly difficult in SQA courses, as these require instruction in formal methods as well as systematic justification of engineering choices, both of which are best facilitated in F2F fashion that implement Think-Pair-Share (TPS) amongst students.

TPS is an active learning technique in which students are allocated adequate time to think individually on a task posed by the instructor, followed by pair discussions, and then as a class discussion. The task given by the instructor is of similar complexity to that which is covered as an example during lecture. Online synchronous activities involve students participating in TPS by working collaboratively as a group on tasks that correspond with concepts covered in the slide-based lectures. This way students learn from each other by thinking individually then sharing ideas in the classroom, thus contributing to better understanding of course content. For assignments and projects students are allocated a portion of the class time to meet with group members and discuss their activities. Groups also have the option to ask the instructor questions aloud that will help other groups to complete their assignments and projects successfully. Delivering these in a hybrid format was required during the fall of 2020 due to COVID-19 restrictions.

The results show that while performance in projects and homework assignments remained constant, final exam performance was significantly ($p < 0.05$) lower in 2020 compared to previous course offerings. We also noted a lower enrollment, higher participatory effort on both instructors and students, and a subjectively decreased feeling of collaboration. Nevertheless, students rated their perceived learning experience as high and regard HyFlex learning facilities as adequate.

In this paper we adopted a HyFlex teaching model that incorporates reduced F2F seating, educational tools such as Blackboard, Panopto, Zoom, Google docs, and Discord. We conclude by discussing some challenges experienced with HyFlex teaching model and recommendations for adopting the teaching model by other instructors who teach CS courses that involve a considerable amount of group activities.

I. INTRODUCTION

Software quality Assurance (SQA) is the process by which adequate planning, reporting, and quality control is implemented during the development of a software to ensure functional and quality requirements are achieved [3]. SQA can be subdivided into several fields, including static SQA (e.g., manual reviews to validate software artifacts such as source code, requirements, or test cases [4]), dynamic SQA (i.e., systematic derivation and execution of test cases to verify correctness [4]), runtime monitoring (e.g., observing live execution under deployment conditions [11]), or static verification (i.e., mathematically verifying invariants [11]). The SQA course taught at SUNY Oswego primarily focuses on static and dynamic SQA. Given the ubiquitous nature of software systems in today's world and people's reliance on them in daily life teaching such important course equips students with the knowledge and skills necessary to ensure systems meet people's expectations for quality and reliability. Therefore, our SQA course is highly team interactive in which instruction relies heavily on formal methods as well as systematic justification of engineering choices. It was for these reasons the course was predominantly taught face- to- face (F2F) prior to COVID-19. With an increase in number of COVID-19 cases, the need for social distancing and temporary suspension of in-person instruction by the state government, we transitioned our teaching model for the SQA course from F2F to HyFlex pedagogical approach to accommodate the largest possible number of students, both remote and local.

HyFlex, short for hybrid-flexibility, is a teaching model where instructors and students have the option to attend scheduled courses F2F or remotely. The course still has a physical classroom and synchronous instructions and the learning outcomes for the course remain the same for all who enroll irrespective of the mode of attendance. It uses existing technologies as well as new ones including those incorporated in learning management systems to accomplish delivery of course content [6].

This paper on HyFlex teaching model is an experience report. The general objective of this research is to share implementation details, discuss challenges and opportunities experienced with HyFlex teaching model, and making recommendations for adopting the teaching model by other instructors who teach CS courses that involve a considerable amount of group activities. We also provide some quantitative comparison of student performance in the HyFlex course offering and previous semesters' offerings.

The remainder of the paper is structured as follows. Section II presents the related work and Section III presents the course design. Section IV discusses quantitative results before Section V lists qualitative experiences from the instructor and the students' perspective. Section VI concludes this paper.

II. RELATED WORK

This section focus on HyFlex teaching model and its application in STEM (Science, Technology, Engineering and Mathematics) discipline. HyFlex, short for hybrid-flexibility, is a teaching model where instructors and students have the option to attend scheduled courses F2F or remotely. Given the rise in the use of technology over the past decade, the ever-changing need of learners in the 21st century and rapid response to challenges such as COVID-19, instructors are

incorporating the innovative teaching strategies that facilitates a more safe and effective learning environment for students. Instructors have been using HyFlex teaching model and a variety of results have been recorded [1, 6, 7, 8, 9].

In a study conducted by Binnewies et al., two instructors designed and delivered a second-year undergraduate information technology course across two campuses using Hyflex teaching model. The model involved students having the option to complete any learning activity and assessment online or F2F. The learning activities and assessment were organized in four different categories, namely: ten learning journal entries to include reflections on the content learned in the lectures, ten lab journal entries to include reflections on the practical activities, three quizzes with multiple choice/true-false questions, and two assignments to be completed in groups of up to three students. Evaluation was conducted on teaching components according to student participation and their quantitative and qualitative feedback. The result of the study shows that students were appreciative of the HyFlex mode delivered [6].

In another study conducted by Sowell et al., implemented HyFlex in a general elective nutritional course consisting of over 500 hundred students. The nutritional course provides a breadth of knowledge in
Science & Engineering (Scientific Literacy). A number of integrated assessments were used in the HyFlex course: exams, a three day diary, and quiz. The results shows that the HyFlex model was very successful with ever increasing enrollment [10].

Prior research in HyFlex teaching suggests that approach is a promising model because students like the flexibility and study results shows that the choice of mode attendance had no significant negative impact on students' performance [1, 7, 8, 9].

While the above research documented positive results on HyFlex teaching approach there is no evidence that shows the use of HyFlex in a highly intensive interactive group course couple with its impact on students' learning during a disruptive period in higher education. The primary aim of this study is to provide an account of the methods used in the delivery of a formal methods group intensive SQA course and the lessons learnt during COVID-19.

III. COURSE DESIGN

The SQA course taught in the Department of Computer Science at SUNY Oswego is a core requirement for the ABET accredited Software Engineering undergraduate program and an elective course for all other department majors (which includes Computer Science BA/BS, Information Science BA, and Cognitive Science BA/BS programs, graduate programs in Human Computer Interaction and Biomedical and Health Informatics, as well as minors in Cognitive Science and Computer Information Systems). Typically instructed in the 15-week fall semesters, the course attracts roughly 20-30 students per semester who already satisfied the prerequisite of having successfully passed an Introduction to Software Engineering course. Students are therefore familiar with the V-Model of software development [12, 13], have extensive programming knowledge and group project experience, and rudimentary knowledge of quality assurance and requirements engineering. The SQA course is loosely paired with a course on Software Safety Requirements Engineering (described in detail in [14]), which is also a core requirement for

Software Engineering majors and elective for others. Students are required to take the Software Safety Requirements Engineering first, however, there are cases in which students may take both courses at the same time. The learning outcomes as filed for accreditation are as follows. Upon completion of this course, students will:

i. [Design] Demonstrate the ability to systematically plan for quality assurance; develop quality management plans; select appropriate QA techniques; derive test cases using appropriate techniques.
ii. [Analysis] Be able to use current tools and methods to plan, analyze, design, test, measure, and manage software products; plan and conduct static and dynamic software artifact quality assurance; gather, interpret, and evaluate quality assurance results.
iii. [Development] Articulate the advantages and disadvantages of quality assurance techniques given the context of development; articulate quality assurance results to developers, managers, and other stakeholders.

A. Face-to-Face Course Approach

Before the COVID-19 pandemic, the course was structured around 6 units of instruction. There were specifically:

1. *Fundamentals and Principles of SQA:* discusses motivation, need, and examples of the perils of inadequate SQA, gives an overview of SQA activities within the context of the V-Model, introduces important terminology, and illustrates ISO 25010 quality criteria and metrics;
2. *Specification-Based Testing*: introduces equivalence class derivation, boundary value analysis, etc. as well as test case definition;
3. *Source Code Based Testing:* considers control flow graph definition, coverage criteria, and data flow-based testing;
4. *Object-Oriented Testing:* includes Binder's [12, 13] OO-Test strategy, state-based testing, scenario-based testing, test of polymorphic structures;
5. *Test Tools:* introduces unit test tools such JUnit, monitoring tools, static QA tools, etc.;
6. *Static SQA:* discusses various review techniques, including a live group-based Fagan Inspection [12, 13] of an example specification or source code.

These units span approximately one to two weeks each, with three 55-minute class meetings per week. The class meetings are roughly equally distributed between lecturing, in-class activities (e.g., solving example problems or discussion of homework assignments), and project presentations. Each unit is paired with one assignment sheet to be solved in self-assigned teams of two students. Assignment sheets comprise exercise problems similar to those discussed in class as part of the unit instruction, which ask the students to produce a specific solution to a relatively trivial problem scope (e.g., a Java implementation of a QuickSort algorithm).

A semester project accompanies all units. In four milestones distributed at selected points of the semester, students are asked to apply the concepts from lectures and solutions avenues from assignment sheets to a non-trivial problem. At the beginning of the semester, students are asked to form teams of four students (typically, two assignment sheet teams form a project team). Each

project team selects a case example project of their own making from previous semesters (e.g., the semester project from their prerequisite Introduction to Software Engineering course). Each project group will apply the techniques discussed in class, one milestone at a time, to this case example project and compile project results in a quality management report. Using this report and staggered, interrelated milestones, students hence evolutionarily compile their results from quality criteria selection, metric definition, and test strategy acquisition (milestone 1), to applying systematic techniques from lecture units and documenting conceptual test case artifacts (milestones 2 and 3), to implementing conceptual test cases (e.g., into JUnit test cases), executing them, and writing up results (milestone 4), including an evaluation if their case example project meets the quality criteria they selected in milestone 1.

Lectures, assignment sheets, and project hence implement the Think-Pair-Share active learning approach by first exposing students to lectures and instructor-led exercises, then requiring them to apply concepts on simple, low-stakes examples with a partner, followed by the application of the concepts on complex context without specific solution and presenting their results. To facilitate this, assignment sheets are graded for correctness of applied technique and discussed in class to resolve misconceptions before project milestones are due. Project milestones are presented by project groups roughly every two weeks, following a similar low-stakes presentation mode as discussed in the literature by Tenbergen et al and Daun et al in which students are encouraged to show their current milestone status "any way they can" [14, 15, 16]. This means that students are encouraged to show preliminary results, regardless of how "incomplete" they believe their work to be, and receive immediate feedback not only from the instructor, but also from other students. In almost every presentation, this uncovers questions and strategies that improve both the presenting groups as well as other groups' work. The instructor grades and returns submitted milestone solutions as well, however in contrast to assignment sheets, where the focus is on correctness, the focus in grading project milestones is on soundness of the QA strategy, engineering choices, and conclusions.

Learning outcomes pertaining to analysis (see above) are hence assessed by assignment sheets, and learning outcomes pertaining to design and development are assessed by the project. A midterm and a final exam assess a selection of all learning outcome categories. In the face-to-face course, all exams were completed on paper, while projects and assignments sheets were prepared and submitted digitally. In-class examples were facilitated using a combination of digital slides and physical dry erase board, as appropriate.

B. HyFlex Implementation Approach

The SQA course taught during fall 2020 enrolled 17 students. Course meetings took place Tuesdays and Thursdays for 1 hour and 20 minutes each. The pandemic prompted higher education instructors to rethink the way course contents are deliver, which lead to the designing of course to work in several formats. For this highly intensive F2F course, the instructor chose to use HyFlex approach due to the uncertainty in disruption associated with the virus. The HyFlex approach brings together two instructional format that are normally used separately: online and F2F teaching and learning activities. Students and instructors have the option to select a combination of format

that work for their schedules and geographical location during COVID-19 [1]. The instructor provides course content and activities to meet the educational needs of students participating both F2F and online. To ensure students are equally gaining the same learning experience, course activities remain the same for both group of students. Over the course of 15 weeks the course content was delivered using three modes:

1. **Face-to-face lectures:** Course contents are taught in person to students who elected to attend class on campus. The number of participants in the four weeks of F2F lectures varied weekly from seven to eleven students. In this instructional format students were spaced 6-feet apart and wore mask to the classroom. There was only one instructor for this course, the instructor also wore a mask and stood behind a Plexiglass panel while teaching. The instructor made use of slides and a white board to provide systematic justification of engineering choices. Group discussions did not take place during the F2F lectures, as lectures were mostly used for technical explanations and examples.
2. **Online synchronous lectures:** In the classroom the instructor made use of Zoom to live stream the activities that were taking place face-to-face. One to two students would enter the Zoom meeting space for the first 4 weeks. Occasionally, the instructor would stop and check the chat feature to answer questions ask and to share online students' ideas.
3. **Online asynchronous lectures:** This format was made available to students who were not able to attend face-to-face or online synchronous lectures because of limitations experienced by some students such as internet connection, stress etc. The instructor provided recorded videos from the F2F sessions, online synchronous lecturers, lecture notes, and online discussion board for students to review at their own convenience and participate in within a specific time. In addition, all exams were administered and submitted online within the set due date.

These three modes of delivery were chosen to assist in the effectiveness of teaching and learning course material, the ability to facilitate students' engagement and meeting assessment needs. It should be noted that the instructor changed between the Face-to-Face and the HyFlex course offerings. Both instructors had ample experience in instructing SQA courses as well as in Face-to-Face and HyFlex environments, but to keep a consistent educational experience for the students, the new instructor adopted the course design from the previous instructor, while making HyFlex-specific adaptations. Throughout the semester, both instructors kept close contact about the course progress, content, and instruction, ensuring a minimal impact on the students' learning outcomes due to change of instructors.

C. Technology used in HyFlex Environment

The following technologies were used in the HyFlex environment

1. Blackboard (Panopto): Face-to-face lectures were recorded using the integrated Blackboard technology in the classroom. PowerPoint slides and whiteboard writing were also captured.

2. Zoom was used to facilitate synchronous access for online students. Students used their Zoom account to securely login to access weekly scheduled class. Zoom breakout rooms were used to facilitate group discussions that addressed course content on that particular session. Group assignments were manually managed based on who attend the online lecture. This way students get to meet, discuss, and share ideas with peers. In addition, students in the classroom talked directly to each other and the instructor, making the most of the in-class context.
3. Google docs: students used google docs to complete group assignments and group projects.
4. Discord: This is an instant messaging and digital distribution platform that students joined to communicate about assignments and project milestones. Students found this platform easier to communicate because of the quickness in message delivery rather than using email.

D. Group Work in a HyFlex Environment

Several studies have pointed to the benefits of learning in groups. Group work promotes students' collaboration, increase students' achievements, increase students' persistence, it assists students in acquiring soft skills such as communication development and teamwork skills, promotes cognitive thinking and provides feedback from peers that leads to learning [5]. Like in previous years, the SQA course implements group work in the form of assignments sheets and projects. Students select their own group members and use various tools to complete their work.

1. Assignment Sheets

Throughout the duration of the SQA course seven group assignments sheets were administered to students. Assignments focus on topics covered during the lectures, distributed and submitted through Blackboard by instructor and students, respectively. The assignment sheets strongly correlated with project milestones like in previous years and were similar in structure and difficulty as the exams. For interactive work, Google suite proved to be extremely helpful tool in the HyFlex classroom. Students used Google docs and slides to complete group activities. Each assignment group consisted of two persons.

2. Project

Four project milestones were assigned to students as a group activity. Group consisted of three to four individuals. Each project milestone builds on the previous milestone and encompassed theoretical concepts discussed in class and exercised during homework assignments in a realistic project, equivalently to previous years.

E. TPS Implementation

Think-Pair-Share (TPS) is an active learning technique in which students are allocated adequate time to think individually on a task posed by the instructor, followed by pair discussion and then one member of the group shares the group discussion for the entire class to discussion [2]. The instructor elaborates on responses and provide perspective where necessary. The task given by the instructor is of similar complexity to that which is covered as an example during lecture. For the first four to six weeks of the syllabus, TPS activities did not occur since students were systematically introduced to the principles and concepts of SQA. Rather, open discussions on systems that failed were discussed as a class. As the course schedule progressed to the modules of formal methods and justifications for engineering practices, TPS was introduced. During this period all students were fully online due to the college closing down as a result of spike in COVID-19 cases.

Online synchronous activities involve students participating in TPS by working collaboratively as a group in Zoom breakout sessions on tasks that correspond with concepts covered in the lecture slides. This way students learn from each other by thinking individually then sharing ideas in the classroom thus contributing to better understanding of course content. For assignments and projects students are allocated a portion of the class time to meet with group members and discuss their activities in breakout sessions. Groups also have the option to ask the instructor questions aloud that will help other groups to complete their assignments and projects successfully.

Overall, group activities provide students with opportunities to engage in critical thinking, collaborating, and problem solving. All of which contribute to students' learning and successful completion of course content. Using breakout sessions was a safe and convenient method for implementing TPS in a hybrid format while cooperating with recommended health practices.

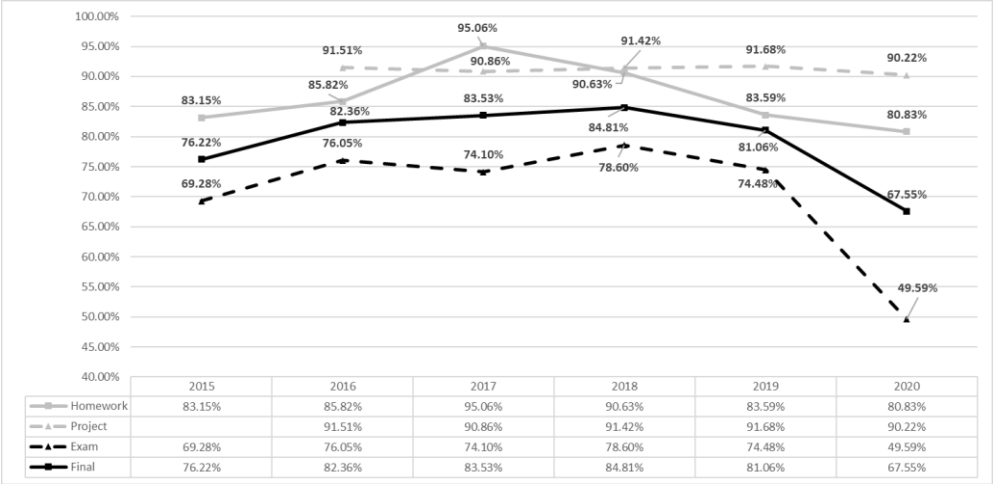
IV. RESULTS

In this section, we provide quantitative evidence to the efficacy of the HyFlex educational paradigm for SQA instruction. Due to difference in sample size we elected to perform comparative analysis between years 2015-2020.

A. Semester Grade Comparison and Analysis

We compared student scores in homework, project, exams as well as the final grades spanning across all semesters from year 2015 to year 2020. Figure 1 shows an overview, but excludes project scores from 2015 since the project was graded on a pass/fail basis (rather than with a graded score) in that semester. As can be seen, homework and project scores remained constant across all six semesters, including the 2020 Hyflex semester. However, exam scores reduced dramatically in 2020. Since final grades are naturally a composite of homework, projects, and exams, the final grade also fell in 2020. To investigate possible reasons for this occurrence we compared the 2020 HyFlex semester with the previous course offering in 2019. The 2019 course offering was

essentially the same as the 2020 offering, with exception of the adopted HyFlex modifications and having the course taught by a different instructor (from 2015 through 2019, the instructor was the same). Hence, we also performed comparative analysis between both instructors' first time teaching the SQA course, which is 2015 and 2020 respectively.



	2015	2016	2017	2018	2019	2020
Homework	83.15%	85.82%	95.06%	90.63%	83.59%	80.83%
Project		91.51%	90.86%	91.42%	91.68%	90.22%
Exam	69.28%	76.05%	74.10%	78.60%	74.48%	49.59%
Final	76.22%	82.36%	83.53%	84.81%	81.06%	67.55%

Figure 1: Semester Results from 2015-2019 Face-to-Face Semesters and the 2020 HyFlex Semester

To compare the semesters, we calculated Two-Sample t-Tests on 2015 vs. 2020 and 2019 vs. 2020 results. Tables 1, 2, and 3 show the t-Test results for homework assignments, exam scores, and final grades, respectively. Due to the different grading scheme of the project in 2015 and the generally linear behavior of project grades from 2016 to 2020, we excluded project grades from this analysis. For all t-Tests, F-Tests were conducted to verify normal distribution of data. Instances where normal distribution is not satisfied are marked with "U" in Tables 1, 2, and 3 to signify that the t-Test variant assuming unequal variances was used. To account for differences in course enrollment, we calculated the statistical power. Significant results and high statistical power are highlighted in bold and marked with "*******".

Table 1: Statistical Comparison of Semester Results: Homework Assignments

	2015	**2019**	**2020**
Mean	83.15%	83.53%	80.82%
Variance	3.52%	0.51%	4.96%
Sample Size	24	31	15
dF	26	15	
F	0.707 (U)	0.101 (U)	
p	0.646	0.739	
Power	0.0004	0.0008	

Table 2: Statistical Comparison of Semester Results: Exam Scores

	2015	2019	2020
Mean	69.28%	74.48%	49.58%
Variance	3.86%	1.54%	1.19%
Sample Size	24	31	15
dF	37	31	
F	3.238	1.292	
P	**< 0.00109 *** **	**< 0.0001 *** **	
Power	0.417	**0.995 *** **	

Table 3: Statistical Comparison of Semester Results: Final Grades

	2015	2019	2020
Mean	76.22%	81.06%	67.55%
Variance	0.32%	0.56%	1.02%
Sample Size	24	31	15
dF	37	22	
F	3.163	0.551	
p	0.097	**0.0001 *** **	
Power	0.023	**0.797 *** **	

Results show that students had a significantly higher final grade average in 2019 than in 2020 with high statistical power. The final grade difference was approaching but did not achieve significance between 2015 and 2020. This was likely due to the also significant difference in exam scores in both comparisons: students had significantly lower exam scores in 2020 than in 2019 with very high statistical power, but with low statistical power between 2020 and 2015. Homework scores showed no significant difference because homework in 2020 did not differ from those assigned in 2015 or 2019.

This confirms that unsurprisingly, exams were the main contributor for lower final grade performance during the HyFlex semester. In addition, results in exam scores seem to indicate that the experience level of instructors was not a contributing factor to students' performance. This is supported by the fact that final grades in 2015 and 2020 were comparable. Since in this course, exams reflect the same type of problem as the problems assigned for homework, one would expect students to perform equally well in exams. However, between 2019 and 2020 circumstance surrounding the pandemic (which, as is widely acknowledged, impaired students' ability to achieve academic success) impacted the exams to a considerable degree, yielding lower final grade results.

It must be noted that while the Face-to-Face offering employed paper-based exams, while in the HyFlex offering, exams were prepared and collected digitally (i.e., through the LMS). We believe that this mode of preparation may at best only have negligibly impacted exam scores. Assignment sheet tasks and exam tasks are very similar in terms of wording, complexity, length, and intellectual challenge as the purpose of assignment sheets is to prepare for the exams, using realistic problems.

To assist students and focus their attention on intellectual challenges (as opposed to challenges in presentation), we provide templates to fill in solutions in both course offerings. These templates are the same for assignment sheets and exams as well as digital preparation and paper-based completion. In other words, we conclude that whether or not exams were prepared on paper or digitally had no impact on exam scores because (1) students were familiar with digital preparation and (2) students were familiar with the solution templates.

The fact that students performed well between all three statistically compared years in homework suggests that HyFlex and F2F instruction are comparable in terms of teaching technical skills and formal methods to students. One could expect that students are capable of learning and solving SQA problems in HyFlex environment just as well as in F2F. Yet, HyFlex cannot undo the confounding negative effects students experience through external stressors, specifically the pandemic. We are confident that instructor-specific effects were minimized due to the experience-level and close collaboration throughout the semester between both instructors.

B. Student Evaluation Comparison

SUNY Oswego is a four-year teaching-intensive comprehensive public university. Evaluations of courses by students are a core asset to improve courses at our institution. From 2015 to 2019, student evaluations were conducted using a 36-item questionnaire instrument, where most items were answered on a 6-point Likert scale. This instrument has been developed several decades before either instructor joined the university and has traditionally been used to assess all department courses, however without specific focus on educational scenarios other than traditional face-to-face instruction. In early 2019, the need was recognized to modernize this instrument and initial discussions had been undertaken in the department in the fall of 2019. The new version of the instrument did not become available for use during fall 2019. The COVID-19 pandemic drastically accelerated this endeavor and the department created a new 28-item instrument. This instrument was created and validated in spring 2020, and was revised and formally adopted in spring 2020.

The instruments between the HyFlex offering in 2020 and F2F offerings in 2015-2019 therefore differs to a large degree. Ten (10) instrument items remained the same across all six course offerings. These were exclusively related to the course design and course content. We computed the agreement score for all items and converted it into a percentage reflecting the "score" students assigned to the course (both the old as well as the new instruments and raw data are available upon request). Results are shown in Figure 2. Please note that questions pertaining to instructor availability and grading policy are not included in the below results because these policies remained the same between Face-to-Face and HyFlex offerings and therefore did not impact the students' perceived course quality.

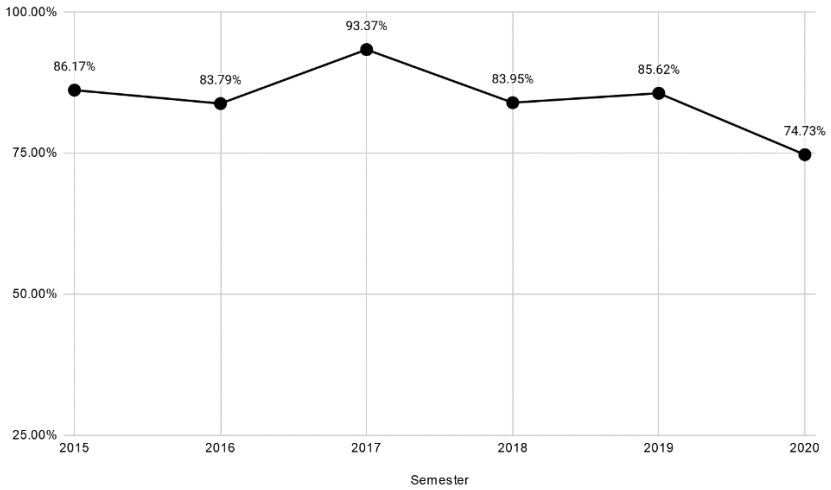


Figure 2: Comparison of Student Evaluations across all six course offerings

As illustrated in Figure 2, student evaluations as measured by the 10 shared instrument items remained comparatively constant across semesters. The two notable dips towards the positive in 2017 and negative in 2020 seem to coincide with the semesters in which homework grades were particularly high or low, respectively (see Figure 1). This suggests a relationship between students' evaluation of the SQA course and the grade they receive during semester assignments. This finding partly confirms undergraduates' preoccupation with grades, as we reported in [16]. Due to the subjective and non-parametric nature of student evaluations, we refrained from calculating inferential statistics.

As outlined above, the purpose in redesigning the survey instrument was to account for non-traditional face-to-face instructional methods in course evaluations, such as HyFlex or asynchronous online courses. The new survey instrument hence specifically asks students to evaluate the use of online and in-person instructional methods, resources, and learning facilities across five special instrument items. Student evaluation frequencies for the 2020 for the 10 responding students are shown in Figure 3. Therein, darker bar segments include higher agreement levels, percentages are the number of students selecting this ordinate as their answer. A majority of students agree or strongly agree to the notion that online and face-to-face as well as synchronous and asynchronous facilities were adequate and assisted their learning. However, it also becomes apparent that students have no desire for more online and asynchronous content.

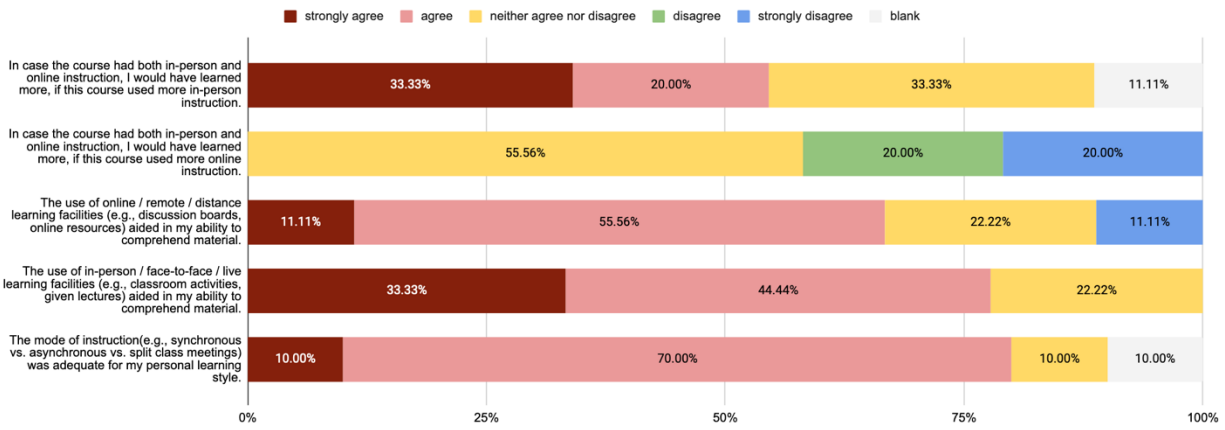


Figure 3: Student Evaluation of Online and In-Person facilities in the 2020 HyFlex Offering (n=10).

We interpret these results twofold. On the one hand, this seems to suggest that the online and asynchronous facilities presented in this HyFlex format were adequate to facilitate learning. However, we can also conclude on the other hand that students will prefer synchronous in-person instruction, if available. Whether or not these results are impacted by the generally low perceived enthusiasm and high perceived anxiety due to the COVID-19 pandemic must be assessed through repetition in future semesters. Instructor-specific feedback from students was generally positive. Both instructors enjoy a friendly, casual, but academically oriented relationship with their students. Hence again, we are confident that instructor-specific effects were minimized.

V. EXPERIENCES OF HYFLEX ENVIRONMENT

The instructor for the fall 2020 SQA course had prior experience in teaching online courses, however, not as highly interactive as the SQA course. The university's center for excellence in learning and teaching provides multiple resources on the topic of teaching strategies. Nonetheless, given that this was the instructor first semester at the university, this circumstance prevented the instructor of the fall 2020 SQA course to take full advantage of the available resources.

Teaching during the time of COVID-19 presents some challenges, yet it also provides rapid means of adaptation in pedagogical approach. Highlighted are some of the things that worked and challenges faced when teaching SQA using a HyFlex model.

What Worked: Students were appreciative of being able to attend class F2F and were highly interactive with peers and instructor as they participated in discussions aloud. In HyFlex environment, the instructor was able to give the same activities to all students irrespective of their location in a safe environment. Using online breakout rooms made it easy and seamless to create and manage small teams of three to four individuals and assign students to different teams for every discussion. Students preferred small teams because it facilitates better TPS since it give each participants an opportunity to focus more and share their perspective eventually.

The chat feature in the virtual environment was identify as an effective tool available to students for use. Firstly, it provides students with a place to ask questions on difficult to understand topic while the instructor is presenting without disruption. Secondly, when students are presenting the chat feature provides an outlet for other students to respectfully comment and react to their peers' presentation. In this manner active listening, learning and staying engaged are encouraged. Thirdly, students who did not like asking questions out loud made use of the chat to comment or ask questions proceeded by instructor or other peers' explanation if necessary.

What did not work: For the first four weeks in the physical classroom it was very challenging with regards to **technical issues**. The instructor had to manage a desktop computer and a laptop. The laptop was used to facilitate online students' virtual presence and the designated computer in the classroom was use for presenting lecture slides and capturing recording (both lecture material, F2F discussions and whiteboard explanation via Panopto). This pedagogical set up was exhausting to manage, time consuming and did not provide the best learning environment for online students. *Online students experienced difficulty in:*

- Seeing what was written on the physical whiteboard that is equipment in the classroom (first 4 weeks). That is, given the technology used in the classroom students online were not able to see the physical whiteboard when the lectures were being presented in PowerPoint slide mode. On the other hand, when the lectures were not in PowerPoint slide mode, the visibility of the physical whiteboard was poor for students logged onto Zoom, see Figure 4.
- following along on the slides because they were not hearing clearly
- Hearing what students in the F2F session was discussing with the instructor due to students wearing masks. As a result few students attended online and opted to watch recorded lectures.
- remote students participation in classroom discussion was absent during the first four weeks

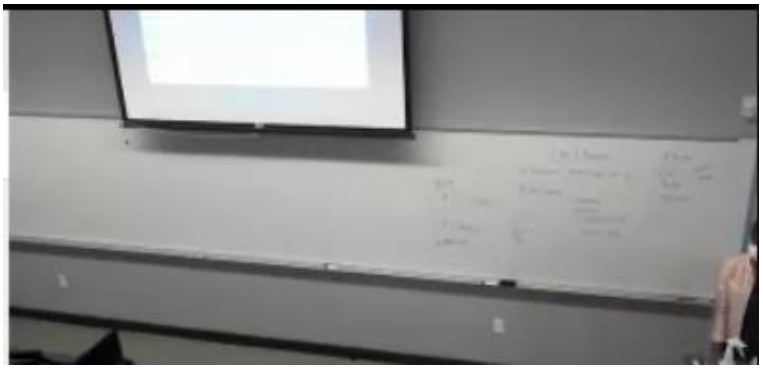


Figure 4: Video Recording of Hardwired Classroom Whiteboard

As the semester progressed, infection rates across the state mandated gubernatorial order for campuses to move online for two weeks. Before this happened, we noticed that only few (i.e., two to three) students participated asynchronously in the first four weeks. This number was approximately the same after the course shifted entirely online after the mandate to transition to online instruction occurred. However, for the SQA course, all students and instructor elected to complete the remaining ten weeks of the course fully online irrespective of location (on campus

or off campus). After that decision, the HyFlex format was maintained. Recorded online synchronous class meetings replaced the recorded class meetings and were made available to asynchronously participating students. Nevertheless, as the semester moved on, the number of students participating asynchronously increased steadily to a point where live attendance was reduced to merely three to five students on average towards the end of the semester.

Preparing course material for online teaching required a lot more time and adjustment to a different format than F2F. Students' complaints were more focused on having a deeper understanding of the course material, specifically formal methods and mathematical justification for a given choice. The absence of a whiteboard for the purpose of explaining and teaching concepts contributed significantly to this feedback. Since digital tablet or stylus hardware was unavailable to the instructor, hand-drawn figures on online white board websites were cumbersomely hand-drawn using the mouse and an inadequate replacement for a physical white board. This stems from the fact that there was minimal use of online whiteboard to facilitate a better understanding of the formal methods and their justification in a simple format. The instructor was not equipped with required equipment to make effective use on online whiteboard.

VI. CONCLUSION

Overall preparing course material for and teaching the SQA course in an online environment during COVID-19 was time-consuming and draining which resulted in physical and mental exhaustion. Students reported similar levels of exhaustion because all breaks were cancelled for that semester. While this shared exhaustion created a mutual bond between the instructor and the students, the impact on students' grades was considerable. For the future, strategies for instructors in a highly interactive course such as a HyFlex environment that we hope to assist in improving students' performance are as follows.

- Reduce course material to easily digestible chucks of information. Quantity of information should take a lower priority than quality of information.
- Incorporate a balanced mix of synchronous and asynchronous activities. Add discussions, students' presentations on particular topics and have students complete interval reflection on course material.
- Insert one or two wellness day break in your schedule to help instructors' and students' recuperation from mental fatigue. This has been made university policy for the spring '2021 semester

Overall students were able to learn in a safe environment and evaluated the HyFlex teaching model positively. HyFlex seems adequate to teach formal methods and technical skills, but cannot undo extra-curricular stressors. Moreover, instructor effort is considerably higher by several orders of magnitude

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