Replicating and Unraveling Performance and Behavioral Differences between an Online and a Traditional CS Course

David Joyner
College of Computing
Georgia Institute of Technology
Atlanta, GA USA
david.joyner@gatech.edu

Melinda McDaniel
College of Computing
Georgia Institute of Technology
Atlanta, GA USA
mcdaniel@cc.gatech.edu

ABSTRACT

In January 2017, a major public research university launched an online version of CS1 targeted at on-campus students to address rising enrollments and provide students with flexibility in their schedules. Prior research on this class has found positive outcomes: students in the course achieve the same learning outcomes as those in a traditional course, while reporting a lower time investment to reach those outcomes and a high level of student satisfaction. This research builds on that prior work in two ways. First, it replicates the findings from that earlier semester with an entirely new semester of students. Second, it delves deeper into the student experience within the online course and its traditional counterpart. This deeper analysis focuses specifically on the differing ways in which students in each section allocated their time, whether or not students in either section accessed the opposite section's material, and their future preferences in online vs. residential CS classes.

CCS CONCEPTS

• Social and professional topics~CS1 • Applied computing~ Distance learning • Applied computing~E-learning

1 Introduction

Over the past several years, universities have seen a dramatic rise in enrollments in computer science classes. Part of this is due to the rising number of entering computer science majors [16], but it is also because of the rising number of universities requiring computer science for all students, regardless of major [17]. This trend has run into the difficulty many schools and universities have in attracting computer science teachers, a trend well documented in the K-12 space [1] but persistent in higher education as well.

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To address these rising enrollments, one major public research university in the United States launched an online version of one of its CS1 classes in January 2017. By offering the class online, the university aimed to bypass many of the constraints on course capacity, particularly lecture hall capacity and scheduling. However, online classes have been met with deserved skepticism: some studies have shown negative outcomes from online courses relative to their traditional counterparts [6][15], while others have found comparable or even advantageous outcomes [3][5].

To investigate this skepticism, significant research has been devoted to this online CS1 class to ensure that student learning outcomes and the student experience are both commensurate to traditional delivery mechanisms. An online section can only be considered to successfully raise capacity to teach CS1 if the product remains comparable. Thus far, that research has found positive outcomes: students in the online section learn at least as much as students in a parallel traditional offering, both overall [8][10] and when subdivided by prior CS experience, with some tentative evidence suggesting the online course may be specifically advantageous for students with prior negative CS experiences [9]. Students also report more positive perceptions of the online experience, and report spending less time per week on the course despite the comparable learning outcomes [8].

This prior research, as well as trends in online learning research, has led to additional questions. First, there is the question of replication: prior research has focused on the initial class two semesters, Spring and Fall 2017, each of which may have had confounding issues affecting the results. Do the results seen in these semesters replicate in a new term? Additionally, not all offerings are equal; changes are made between semesters. Do the results replicate in despite the changes made?

Second, the results themselves raise interesting questions. If students in the online section achieve the same learning outcomes in less time, what specific tasks are requiring less time? Are they using shared supporting infrastructure in the same way? How do they rate the perceived value of components accessible to both course sections?

This research addresses these questions. First, we will perform the same analysis from previous semesters on a new semester's data to identify what trends replicate. Then, using new questions added to the courses' surveys, we will investigate the behavioral differences among students in the two sections. Finally, we will also replicate the analysis of students' perceptions of the course to see if perceptions have changed with the modifications made for the Spring 2018 semester.

2 Course Background

The university's CS1 class teaches introductory Python, covering variables, operators, conditionals, loops, functions, error handing, strings, lists, dictionaries, files, objects, and algorithms. The online class mirrors the traditional version's learning goals but uses its own assessments and instructional materials to leverage the online medium.

The major differences between the courses flow from the affordances of teaching online. While the traditional version has three lecture periods per week and take-home homework assignments, the online version has short 5-10 minute pre-recorded videos with smaller problems interspersed for frequent practice. The traditional version includes human evaluation, while the online version exclusively uses automated evaluation; the feedback and results are returned to students immediately. The two versions have similar supporting infrastructure (a course forum, a help desk, and a recitation), use the same pre-test, post-test, and course surveys to compare between the delivery methods, and are taught by different instructors.

2.1 Online Course Design

A full background of the design of the online course is available in prior work [8]. At a high level, the online course is comprised of 455 videos averaging 2 minutes in length, in line with best practices identified by researchers studying MOOC engagement [4]. Students also use an adaptive textbook written for the class on McGraw-Hill's SmartBook platform, following an identical organizational structure to the course lecture videos.

Lecture videos are rapidly interspersed with exercises. Some exercises are multiple choice or fill-in-the-blank, while others require live coding to pass an automated grader. The textbook, similarly, has embedded multiple choice and fill-in-the-blank questions. These questions are completed for course credit, with unlimited attempts and feedback given on incorrect answers.

After each major chapter of the course, students complete a problem set comprised of additional multiple choice, fill in the blank, and live coding problems. After each major unit of the course, students complete a timed and proctored exam featuring more of the same structure of problems, including live evaluation. Altogether, students complete over 1,000 multiple choice and fill-in-the-blank problems and 450 coding problems.

2.2 Semester Details

This analysis takes place during a standard 17-week semester. Students in the online course are given a recommended calendar to follow, although significant flexibility is built in. The major deadlines are the four course tests, at which point students are required to have all prior work completed; outside of these deadlines, however, students have flexibility.

As part of the semester, students have access to three additional resources: a course forum, a help desk, and recitation. The forum is the recommended place to ask questions and receive help from classmates or the teaching team. The help desk allows students to come for in-person help with one of the teaching assistants. Recitations are optional meeting times, during which the teaching assistants deliver supplemental lectures, provide practice materials, and answer questions.

3.2.1 Semester Changes. Although we consider this a replication study to test the same pair of courses during a new semester, there are always changes that occur between terms. During this semester, the online section introduced two new features: students are now required to complete four 30-minute check-ins with teaching assistants during which they receive additional feedback, and students are now required to complete approximately 75 additional "advanced" problems specifically constructed to test their knowledge on more advanced concepts. Differences observed this semester in outcomes, time invested, or attitudes may be due in part to these differences.

3.2.2 Semester Demographics. During this semester, we observed similar trends to prior semesters in enrollment patterns: the online section drew fewer students with no prior experience (51.2% vs. 64.2%) with statistical significance (X^2 = 8.462, p = 0.0036). However, there was no statistically significant difference in the number of students who had previously *completed* a CS course; online students were more likely to have previously failed or withdrawn, while traditional students were more likely to have never enrolled in a CS class before Significant differences were also seen in employment, major, and age: online students were more likely to be older, employed, or business majors, while traditional students were more likely to be younger, unemployed, or engineering majors. A more thorough breakdown of the differences in student demographics between the sections is available in [12].

3 Performance Differences

To assess performance differences, students in both the online and the traditional version of the class complete the SCS1 inventory, a standardized and validated instrument for assessing introductory CS knowledge [14], at the beginning and end of the semester. Students in both sections receive course credit for completing the inventory regardless of their performance on it.

3.1 Overall Differences

Table 1 shows the pre-test, post-test, and change in scores for students in the online and traditional sections in Spring 2018. Change scores are calculated by subtracting the pre-test score from the post-test score for students who completed both tests.

Notably, while previous semesters have seen no overall statistically significant difference in performance [8], this semester was different: while there was no statistically significant difference between traditional and online students on the pre-test, statistically significant differences were present on both the post-test and in the change in test scores. Students in the online section improved their scores more and ultimately performed better than students in the traditional section.

Table 1. Pre-Test, Post-Test, and Change (Post-Test – Pre-Test) scores for students in the traditional and online sections. A Student's t-test is used to check for statistically significant differences among these scores.

	Pre-Test		Post-Test		Change	
	Trad.	Online	Trad.	Online	Trad.	Online
Mean	6.25	6.75	8.37	9.81	+2.26	+3.58
SD	3.72	4.29	3.90	4.65	4.70	4.58
N	286	204	171	158	168	158
t	1.3946		3.0416		2.5646	
p	0.1638		0.0025		0.0108	

3.2 Differences by Prior Experience

Previous analyses have also segmented students by their prior experience to investigate for more fine-grained differences in performance. Specifically, it was hypothesized—and later observed [9]—that students who had previously failed or withdrawn from a CS course may be more advantaged by taking the online section. Weak evidence was observed that students with prior expertise or informal experience might be advantaged by the online section as well.

Table 2 to the right shows the segmented scores based on prior experience for this semester's data. Students were asked to report their level of prior CS experience on the start-of-course surveys in both sections. Students who reported previously withdrawing from or failing a CS class are classified as "Prior Experience". Students who reported previously completing a CS class are classified as "Prior Expertise/Success". Students who reported informal or self-taught ways of learning CS are classified as "Informal Experience". In most cases, students selected these options from a multiple-choice question; 21 students reported "other" experiences, but their responses were ultimately coded as one of these four categories (e.g. "I took APCS in high school" was coded as "Prior Expertise/Success").

In this term, too few students classified as Prior Experience were present in the traditional class for a meaningful comparison. Additional evidence emerged supporting the suggestions of prior work [9] that students in the online section classified as Prior Expertise and Informal Expertise improved more or performed better at the end than their traditional counterparts. However, the number of t-tests and the lack of corroborating results from the post-test (for Informal Experience) or change scores (for Prior Expertise) weakens this potential conclusion.

4 Behavioral Differences

These results suggest that students in the online section are improving more and ending the class with higher post-test scores. That alone may have multiple explanations that may or may not be related to the online delivery mechanism. For example, it may be the case that students in the online section also attend the traditional lectures, make heavier use of supporting infrastructure, or simply are required to spend more time on the class. To investigate these, the post-course survey in both sections asked students to reflect on several of their behaviors during the semester.

Table 2. Pre-Test, Post-Test, and Change scores for students in the traditional and online sections, segmented by prior CS experience. A Student's t-test is used to check for statistically significant differences among these scores.

No Prior Experience

	Pre-Test		Post-Test		Change	
	Trad.	Online	Trad.	Online	Trad.	Online
Mean	5.19	9.45	8.19	8.84	+3.28	+3.91
SD	2.50	4.92	3.93	3.79	4.21	4.38
N	183	105	118	95	115	95
t	0.6950		1.1238		1.0554	
p	0.4876		0.2262		0.2925	

Prior Experience

	Pre-Test		Post-Test		Change	
	Trad.	Online	Trad.	Online	Trad.	Online
Mean	6.76	7.20	8.00	8.93	+0.83	+2.29
SD	3.25	4.92	2.53	3.22	2.86	4.38
N	17	20	6	14	6	14
t	0.4245		0.6249		0.7419	
p	0.6738		0.5399		0.4677	

Prior Expertise/Success

	Pre-Test		Post-Test		Change	
	Trad.	Online	Trad.	Online	Trad.	Online
Mean	8.19	9.45	8.89	12.73	+0.34	+2.91
SD	4.59	4.92	3.68	5.91	5.34	5.38
N	64	55	35	33	35	33
t	0.1493		3.2358		1.9729	
p	1.4514		**0.0019**		0.0527	

Informal Experience

	Pre-Test		Post-Test		Change	
	Trad.	Online	Trad.	Online	Trad.	Online
Mean	9.05	7.96	8.83	10.31	-1.25	+4.13
SD	5.71	6.45	4.91	5.25	4.81	4.22
N	22	24	12	16	12	16
t	0.6029		0.7579		3.1412	
p	0.5497		0.4553		**0.0042**	

4.1 Cross-Attendance

One prior hypothesis was that students in the online section might be attending the traditional lectures as well. It has also been noted that students in the traditional section can access the online course material through its parallel publicly available Massive Open Online Course (MOOC). Thus, the post-course survey asked students to report how frequently they consumed the other version's materials.

Throughout the rest of this research, we use a X^2 test to check for significant differences in proportions of students between the sections. Here, both sections used the other's materials at comparably low rates: 87.4% of students in the traditional section reported "never" using the online section's course materials, and 89.6% of online students reported that they "never" attended in-person lectures (X^2 = 0.444, p = 0.5053).

4.2 Use of Supporting Infrastructure

Both the traditional and the online sections take advantage of three pieces of supporting infrastructure: a help desk, a scheduled recitation, and a course forum. These three environments are described under section 3.2.

A possible explanation for the differences in performance noted above is that students in the online section, liberated from the time commitment of weekly lecture attendance, may use the supporting infrastructure more heavily. Thus, our post-course survey asked students in both sections to report how frequently they used each environment, and how useful they assessed each to be. For frequency, students were given ranges (e.g. 1-2 times, 3-5 times), which were distilled into two categories for analysis. For recitation attendance and help desk visits, students were divided between those who reported attending two times or fewer and those who reported attending three times or more. For course forum usage, students were divided between those who reported using the forum three times or fewer and those who reported using it four times or more. Table 3, below, shows these usage patterns and student evaluations of each environment's usefulness.

Table 3. Frequency with which students in each section reported using the help desk, recitations, and forum.

		Traditional	Online
Help Desk Visits	% <= 2 visits	52.9%	74.9%
	N	208	175
	X^2, p	19.672, < **0.0001**	
Recitation Visits	% <= 2 visits	18.8%	85.1%
	N	208	175
	X^2, p	166.724, < **0.0001**	
Course Forum Usages	% <= 3 uses	76.9%	67.5%
	N	208	175
	X^2, p	4.211, **0.0402**	

Based on the reported usage patterns, online students use the help desk and recitations far less often than their traditional counterparts. The most pronounced difference is in recitation attendance: only 14.9% of online students reported attending 3 or more recitation sessions, while 81.2% of traditional students reported attending 3 or more recitation sessions.

A smaller, but still statistically significant, difference is observed on the course forum. Online students make heavier use of the course forum than on-campus students. This may be due to the apparent parallelism: the traditional class, help desk, and recitations are all in person, while the online class and course forum are online. However, this may also be unrelated to the medium and more related to the teaching teams' respective involvement in the forum: students were asked who responded to most of their questions on the forum; 55.2% of students in the online section reported that the instructor responded, compared to 9.8% of students in the traditional section (X^2 = 90.385, p < 0.0001). 42.2% of traditional students reported a teaching assistant answered, and 20.1% reported another student answered, compared to 2.9% and 15.7% respectively for the online section. Therefore, online students may have gravitated toward the course forum as a place where the instructor was visible and active in answer questions.

Regardless of their cause, these differing usage patterns are reflected in the reported rating of the usefulness of the help desk and recitations. Students were asked to rate the usefulness of each on a 7-point Likert scale. These results are reported in Table 4 below. A Mann-Whitney U Test was used to compare for differences here and in all comparisons of Likert-scale responses due to the nonparametric nature of Likert scale data. Scores are shown as numeric averages of the reported values.

Table 4. Average 7-point Likert-scale ratings of the usefulness of the help desk, recitation, and course forums, and results of a Mann-Whitney U Test comparing them.

		Traditional	Online
Help Desk	Mean	4.94	4.32
	Z, p	4.5868, < **0.0001**	
Recitation	Mean	5.05	4.06
	Z, p	7.8772, < **0.0001**	
Course Forum	Mean	4.65	5.73
	Z, p	-6.7937, < **0.0001**	

As expected, perceptions of usefulness followed the usage patterns: traditional students rated the help desk and recitations as more useful with statistical significance, and online students rated the course forum as more useful with statistical significance. It is interesting that even though 2/3rds of the online class used the forum 3 or fewer times, the vast majority rated it as positively helpful.

4.3 Allocation of Time

Given that the two courses have different assessments, it may be the case that students in the online section learn more solely because the assessments demand more practice time. Discussions with teaching assistants who have worked on both courses reflect this: they note that the frequently interspersed practice means that online students tend to do more actual coding in the class. Thus, we ask students to report two details regarding their time investment: the total time they spent on the class, and how that time was allocated. While it is known from multiple fields that self-report is not accurate to reality [18], we hypothesize that there is no systematic under- or over-reporting bias specific to one section against the other; this assumption, however, ought to be tested in future research.

For total time, students were offered a few categories: fewer than 5 hours per week, 5 to 7 hours per week, 8 to 10, 11 to 13, or 14 or more. Analysis divided students into two groups: those reporting 7 or fewer hours, and those reporting 8 or more hours spent. 41.0% of 210 traditional students reported spending 7 or fewer hours per week on the course; 71.1% of online students reported spending 7 or fewer hours per week on the course. This difference is statistically significant (X^2 = 35.0.36, $p < 0.0001$). Thus, it is not the case that online students—based at least on their self-reported time investment—are simply spending more time; in fact, it appears they are spending significantly less time.

This result was observed in previous semesters [8], but it was noted that we are unsure of what activities students include in their reported time investment. For example, as an online course, students do not walk to and from class. Are traditional students including this in their calculation? This alone could account for the difference in time investment. So, in Spring 2018, we asked students to self-assess what percentage of their total time spent on the class was allocated to different activities. As above, we note that these numbers may not closely resemble reality, but we hypothesize that they are useful as a point of comparison.

Activities are grouped into the following categories: lectures, support (help desk, recitation, forums), active work (homework, labs, assignments, tests), studying, and other. When selecting other, students could report what behaviors were not captured under other categories. Students whose total percentages added to below 95% or above 105% were excluded from the analysis. Table 5 below reports the average percent allocation to each of these categories in the Spring 2018 sections.

Table 5. Self-reported average time allocation to five categories of class-related activities in the traditional and online sections.

	Traditional	Online
Lectures	28.5%	17.4%
Support	15.3%	4.3%
Active Work	47.9%	75.2%
Studying	9.6%	3.0%
Other	1.8%	1.6%

This report significantly unraveled the behavioral and performance differences observed previously. Online students report allocating their time significantly differently: over 75% of their time invested in the course is spent on active work, while less time is spent consuming lecture material, pursuing support opportunities, or studying in general. This difference in active learning time is statistically significant (X^2 = 25.405, $p < 0.0001$). Therefore, while online students spend less time on the class overall, they may spend more time actively engaged in practice.

An option to list "Other" activities intended to capture whether students included unanticipated activities in their time reported. Although "Other" time comprised a small percentage of the reported time, there were a few trends observed: check-ins, review sessions, practice on third-party sites, helping others, reading the textbook, and seeking additional resources for aid.

There may be several reasons for this difference. First, as noted when describing the course design, exercises are frequently interleaved with the lecture material, meaning that opportunities for practice are not relegated to homework or set-aside lab activities. Second, because the course assessments are automatically evaluated, grader time is not a concern: the number of assessments can be increased without demanding additional staff. Third, it has been observed that with pre-planning, pre-visualization, and video editing, recorded videos deliver the same content more efficiently [13]. Fourth, students have reported that because the course material is persistently available, they do not have as strong a need to visit the help desk or attend recitations: if they need additional instruction, the material itself is available. We hypothesize this builds on a perceived greater connectedness between instructional material and assessment in the online course: students in a traditional course may feel the need to consume as much instructional material as possible "just in case"; online, the material is persistently available; if they need it, they may revisit it.

4.4 Summary of Behavioral Differences

To summarize the observed differences, students in the online section are observed more heavily using the course forum, less heavily using the course help desk or recitations. They report spending less time on the course overall, but they report spending a much greater percentage of that time on active learning activities, and significantly less watching lecture videos, using supporting infrastructure, and studying in general.

5 Perceptual Differences

Prior research also noted different student perceptions of the value of certain course components, as well as the overall pace, rigor, and quality of the courses themselves [8][10]. To replicate as much of these previous studies as possible, we performed these analyses on this semester's data as well.

First, students completed 7-item Likert-scale items on the value of seven course components present in some form in both sections: lectures, a textbook, assignments, tests, recitations, the help desk, and the course forum. Results for the last three of these are presented in the previous section; results for the remaining four are in Table 6 below.

Table 6. Student perceptions of the value of four course elements on a 7-point Likert-scale. A Mann-Whitney U Test is used to test significant differences.

		Traditional	**Online**
Lectures	Mean	5.45	5.95
	Z, p	-3.9033, < **0.0001**	
Textbook	Mean	4.06	4.09
	Z, p	-0.0698, 0.9442	
Assignments	Mean	6.02	6.45
	Z, p	-3.5154, **0.0004**	
Tests	Mean	4.86	5.35
	Z, p	-2.8416, **0.0045**	

In line with previous terms' results, lectures, assignments, and tests were rated as more valuable by students in the online section with statistical significance. Interestingly, while the textbook has been rated as more valuable by traditional students in the past, no difference was observed during this semester.

Secondly, students rated the perceived quality, quality compared to other college courses, pace, and rigor each on a 7-point Likert scale. Pace and rigor were both rated on scales of Way Too Slow/Easy (1) to Way Too Difficult/Fast (7), with About Right in the middle (4). Quality was rated on a scale of Bad (1) to Excellent (7). Quality compared to other classes was rated on a scale of Far Worst than Other Classes (1) to Far Better than Other Classes (7), with About the Same in the middle (4). The results of these questions are shown in Table 7 below.

Table 7. Student assessments of the pace, rigor, and quality of the two courses.

		Traditional	**Online**
Pace	Mean	4.17	4.06
	Z, p	0.9984, 0.3173	
Rigor	Mean	4.36	3.99
	Z, p	3.7624, **0.0002**	
Quality	Mean	5.47	5.98
	Z, p	-4.2195, **< 0.0001**	
Quality Compared	Mean	5.05	5.58
	Z, p	-5.2081, **< 0.0001**	

These results generally match prior semesters: pace and rigor in the online course have been reported as closer to “about right”, and quality both on its own and compared to other courses has been rated higher in the online section. Altogether, 66.5% of 203 students in the traditional section and 85.1% of 175 students in the online section rate their class as better (5 or above) than other courses, a statistically significant difference ($X^2 = 17.346$, $p < 0.0001$). Moreover, 88.2% of those traditional students and 98.3% of those online students rate their class as at least as good (4 or above) as other college classes, another statistically significant difference ($X^2 = 14.451$, $p < 0.0001$).

6 Conclusion

This study has aimed to simultaneously replicate and unravel observed differences between students in parallel online and traditional versions of CS1. Prior work noted that students in the online and traditional versions of this university’s CS1 course performed similarly, while this research found that instead, the online students actually achieved superior learning outcomes despite spending less time. In both cases, however, the implicit question exists: how were the online students able to learn as much or more in less time? Delving into this further, this research finds that the online students allocate their time differently, spending more time on active practice. Despite spending fewer total hours on the course material, they spend a greater amount of time on actively practicing.

Given that the courses are taught by different instructors, this could be a product of teacher differences. However, we note that there are several characteristics of the online medium that afford this altered behavior. First, prior research has suggested that video presents a more efficient medium for presenting content than live lecture [4][13], reducing the time students must spend on lecture-viewing. Second, the persistent availability of online lectures means that students need not over-consume “just in case”; they may wait and consume lecture material as needed, further reducing their passive learning time. Third, the deep compatibility between online delivery and online automation means additional practice may be required without hiring additional human support to evaluate student work.

We thus hypothesize that a well-designed online course can achieve comparable or superior outcomes to a traditional course by taking advantage of the online delivery medium’s ability to decrease time spent on passive learning and emphasize active practice. We do not hypothesize this to be inherent in online learning, but rather to be an opportunity that must be leveraged.

6.1 Limitations

Although many of these differences have now replicated across semesters, there remain two major limitations to this study. First, the instructors for the two sections are different. It is difficult to isolate the difference between online and traditional sections in general from the difference between these two instructors’ classes. Both are award-winning instructors and specialists at their respective mediums, and so this study in many ways compares the ideal circumstances for an online class; it should be taken as evidence of the high potential of online delivery, not a guarantee that online delivery will be effective.

Second, given the generally universal high ratings given to the online section, there is the potential for a Halo effect [2]. Under this effect, students appreciate the course in general, and therefore give positive ratings to each individual component, regardless of whether they appreciate that component. Further research ought to elucidate how students leverage individual course components course without relying on self-report.

6.2 Future Work

This analysis has focused largely on reporting broad trends in the two classes rather than more specific relationships among the variables observed. Significant questions remain regarding many of these relationships. We know from prior research that there are relationships between which section is selected and factors like college major, race or ethnic identity, and level of employment; we do not yet know, however, if there are certain such sections that perform better in one section, and moreover whether students are likely to choose the section in which they are more likely to perform well. These questions have particular relevance given data that suggests that the types of students who choose online courses are often those less likely to succeed in them than in comparable traditional courses [7]. Similarly, future work may also look at how fine-grained behaviors correspond to student success, and whether we can automatically intervene with students demonstrating behaviors known to correlate to an increased likelihood of failure. Automated evaluation also provides rich opportunity for systematic evaluation of student answer patterns for tailoring individualized feedback or informing large-scale course revision. Work is underway to use automated clustering to examine patterns in student work [11].

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