CHANGING PERCEPTIONS OF COMPUTER SCIENCE

BY:

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Abstract

Students misperceive computer science as only programming; such misperceptions may contribute to students' negative views and reluctance to join this field of study. The Laboratory for Computer Science creates online lessons for high school students that introduce computing theories in an interactive way. A study was conducted to examine how students' perceptions of computer science change upon completion of these labs. The focus of the study is on the students' perspective of computer science and their place in the field irrespective of their identification with a specific minority group. Identifying whether the stigmas or stereotypes are present with the students that experience these lessons and whether a deeper knowledge of the underlying theories in computer science will change these views is the goal. Based on the student feedback from this study, a standardized method of developing and organizing these student labs was proposed and used to create a series of four labs on Little's Law.

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1. Introduction

A commonly stated concern in the field of computer science education is the low enrollment rates in comparison to other science majors. A number of factors have been explored, from gender stereotypes and social stigmas to the way in which the course material is presented. As can be seen in Figure 1.1 below, enrollment rates for both genders have dropped well below the previous high in 1998. With these rates remaining relatively low in the most recent years, prospective students need the opportunity to learn about the interesting concepts behind the computer science field before a career decision is made.

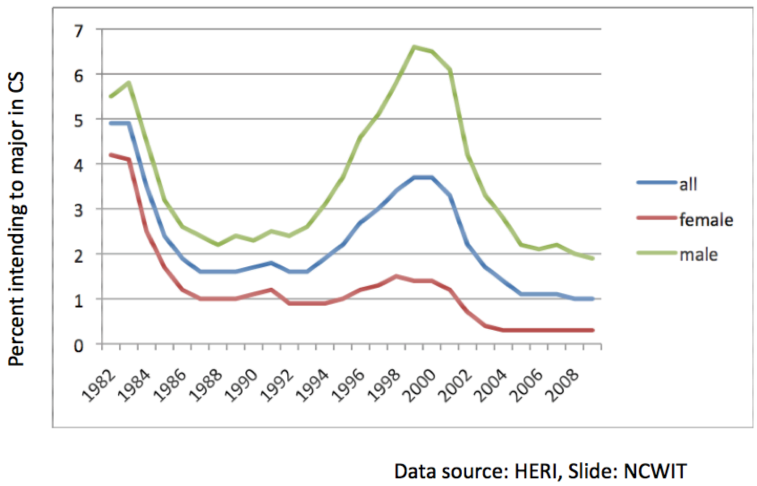

Figure 1.1

Contributing to the low enrollment rate is the impression students receive that this field is solely programming. When computer science classes are offered in middle and high schools, often only the basics of programming principles are introduced. While programming is an important tool, the perception that computer science is only programming is harmful.

The Laboratory for Computer Science (LoCuS) project at the University of Arizona intends to broaden young students' understanding of computer science by introducing them to various theories in computer science through online labs. Few schools in the Tucson area spend as much time on student interaction with concepts in computer science as they do in traditional sciences such as biology or physics. LoCuS is creating labs to help fill this gap. The interactive online lab notebooks guide students through the different steps of the scientific method to test their hypotheses about a central theory in computing in a manner similar to lab notebooks found in chemistry or physics labs. With this broader understanding of the concepts in computer science beyond basic programming, students may show increased awareness of computer science as an exploratory, experimental process. By expanding students' ideas of what computer science consists of, their accurate perceptions of the field may encourage them in their choice of major or career. A study was constructed to examine how high school students' perceptions of computer science change upon completion of these interactive online labs. Based on student responses during the evaluation process, two refinements to the lab development process were proposed and implemented.

2. Related Work

A study by Carter (2006) examined why students who would statistically flourish in the computer science field instead continue in another. This study determined that one main contributing factor is that these students do not have a complete understanding of what topics are covered in a computer science degree. In addition, several students negatively described computer science as a very solitary, repetitive activity. In an effort to address this gap in students' understanding of the foundation of computer science, the CS Unplugged program was developed. This program provides a hands-on learning summer experience targeted primarily toward elementary schools students (Bell, Alexander, Freeman & Grimley, 2006). By removing computers from the lessons altogether, these activities were able to separate the central concepts in computing from the programming aspect. It was shown by Lambert that this process did increase students' overall interest in the computing field (Lambert & Guiffre, 2009).

Due to decreasing enrollments at Siena College, a study was undertaken to determine the effectiveness of a one-day program in career exploration for the Computer Science Department in recruiting local students to their degree program (Egan & Lederman, 2011). It was found that immersing students in computer science instructional sessions and activities did significantly diminish their perception that solitary programming constitutes a majority of computer science activity. A similar study implemented at Georgia Institute of Technology focused on analysis of student retention (Biggers, Brauer, & Yilmaz, 2008). Their computer science department, like many others, was faced with students who choose to study computing but ultimately leave for a different major. This study determined that one contributing factor to students switching is their feeling that the topics learned in computing were not applicable to problems outside this specific field.

3. LoCuS Infrastructure

The goal of the LoCuS project is to create a collection of lessons on theories in computer science that are accessible and easily used or contributed to by any student or teacher. This next section describes how this system of labs is organized from development to deployment.

3.1 Content Creation

The LoCuS lab system is constructed so that the writer of a lab needs minimal knowledge of the inner working of the lab itself in order to create the content for a lab (Johnston, Cheepurupalli, Gephart, & Snodgrass, 2012). If a teacher or student would like to contribute their own lab topic, they need only to format their writing into an XML document. This document can be created easily; tags using the angle brackets are added around groups of similar information to indicate how it should appear on the screen, similar to HTML formatting. For example, surrounding the phrase, "`My introduction`", with "`<b>my introduction</b>`" will make it appear as boldface text in the final lab. With XML, personalized tags can be created to represent specialized formatting specific to each project in which it is used. LoCuS has created a set of XML tags that can be used in this way to bring in outside resources, such as pictures or apparatuses.

3.2 Apparatuses

An apparatus is a standalone program that can be used within a lab to better illustrate the concepts being presented (Emmott, Shrestha, & Trame, 2011). For example, as a student learns about the principles of locality in the Locality lab, they are walked through the coloring of a picture in the Coloring apparatus. Based on the way in which the picture is filled in, the student will have access to different statistics that relate to what they are learning in the lab. Lab authors can allow students to open an apparatus at different points throughout the lab to give the students a platform on which to test the theory being presented to them. College students as part of projects in programming design classes and theses have created the apparatuses currently utilized in LoCuS labs.

Two apparatuses were created in conjunction with this project for the Little's Law lab on the theory behind queues. The first apparatus, as seen in Figure 3.1, is the Spreadsheet apparatus that allows basic calculations to be done with numerical data. Users can add new rows and columns to the data set that are created by performing a calculation between existing columns, such as multiplication, negation, or averaging. Any numerical data saved in the comma-separated format can be imported into the Spreadsheet to be analyzed. Names and units can also be assigned to each column and row. The second apparatus is QueueSim, which simulates the queues that form at the cash registers of a super market. An example of this apparatus can be seen in Figure 3.2. The user can control how quickly customers enter the simulation, the number of lines that form, and how quickly each customer is served at the register. Users can then view the data generated by this simulation in the Spreadsheet in order to calculate the various values discussed in the Little's Law lab.

3.3 Lab Environment

Behind the visualization of the lab notebook, there is a system that creates the environment for the user based on the XML document. The content created by the lab author is parsed so that the different formatting options can be incorporated into the display. There are several functionalities that are standard for every lab. In addition to the textual formatting informed by the XML document, the lab also has the ability to offer multiple choice, short answer, or Likert-style questions. These answers given by a student are then saved to a file for future use when necessary.

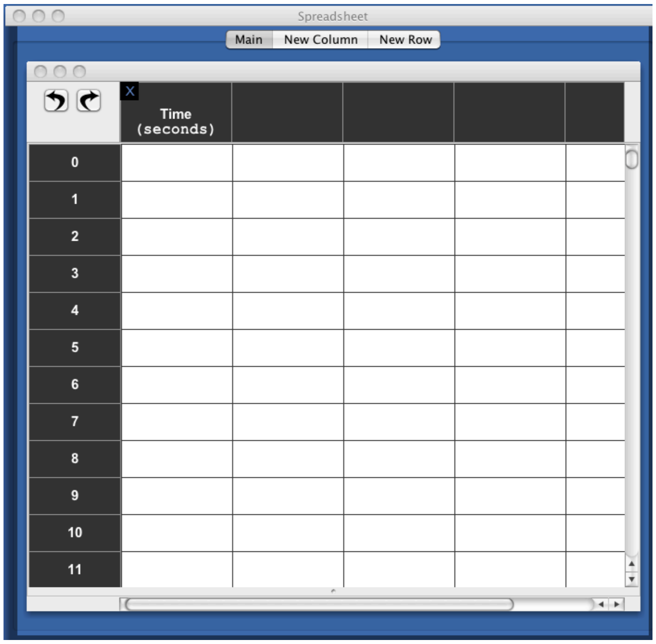

Figure 3.1

Each lab has the same look and feel that allows the student to turn the pages as though it was an actual lab notebook. There is a space for a simulated chalkboard where instructions can be displayed as well as a holding spot for all necessary apparatuses. When the student needs to open an apparatus during the lesson, all necessary data will be automatically loaded and can be opened with one click inside

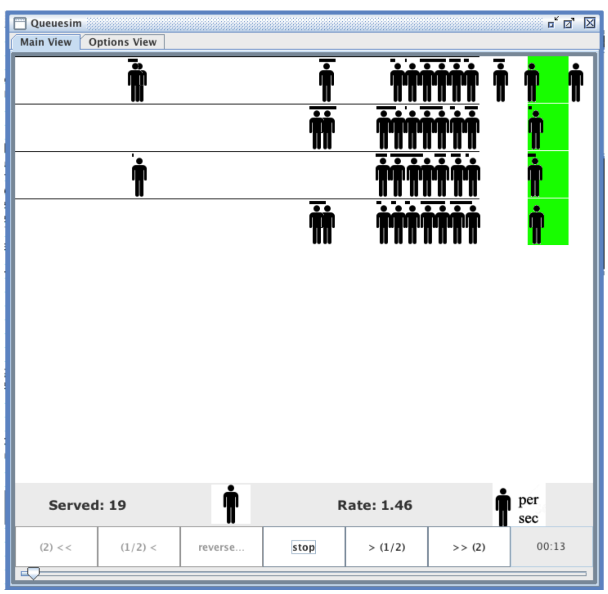

Figure 3.2

the lab notebook. There is also the ability to connect apparatuses during runtime, allowing an apparatus like QueueSim to send information to the Spreadsheet as the data is being generated. All of these functionalities, the apparatuses used by that lab, their input data sets, and the lab text are compiled into one runnable file. These packaged labs are then made available for download on the Internet. From the portal website, an instructor is able to set up a timeframe for their class to access the labs. From here, they are also able to download student responses in a PDF or CSV format for grading purposes.

3.4 Lab Design

These labs are designed for use not only by students in classes, but also as a resource for any teacher or individual interested in Computer Science. Each lab offers a lesson independent of the others and acts as an interactive guide for a student to teach themselves about a basic theory in this field. Within each lab, there are Preliminary, Experimentation, and Evaluation sections.

The Preliminary section introduces the topic in general as well as the tools that will be used throughout, called apparatuses. For example, the lab on Little's Law begins with an explanation in the context of a toll bridge. The Experimentation section of the lab then aids the student in forming and testing a hypothesis related to the topic. In the queuing theory lab, students test the accuracy of Little's Law to accurately predict the relationship between the average number of customers in a queue to the average wait times and the arrival rate. With the newly gained knowledge of how to calculate the three main values associated with this law, the student then uses the Queuing Simulator apparatus to simulate customers in line at a grocery store. The student can interact with the apparatus to change each variable and test how the scenario is affected with live action. This data is then sent to a Spreadsheet apparatus with which the student can perform the necessary calculations to verify their hypotheses. In the Evaluation section of the lab, the students analyze the success of their experiment and complete further application questions to test their comprehension of the material.

The overall look and feel of the lab is designed to resemble the typical lined lab notebook that students use during a chemistry or physics lab. There are places for students to write their observations and answer questions as well as diagrams or models to explain new concepts. Rather than working with beakers or pulleys as they might in a physical lab, the students interact with the visual apparatuses provided along the way. Each lab utilizes at least one apparatus tailored to that concept that helps the student visualize the data being manipulated. For the purposes of this study, a fourth section has also been included at the end of each current lab. This section is a short survey featuring Likert-style questions that analyze how their interactions with the lab may have affected their perceptions of computer science as an intriguing and achievable field of study.

4. Testing Labs in High Schools

4.1 Methods

Two phases of quality control and evaluation were used to evaluate the effectiveness of the labs. Phase one of the project occurred in Fall 2010 and was focused on receiving feedback about the quality of the online lesson content. Students in four high school classes completed the online labs as though they were a classroom assignment for the first two lessons that were developed. The students were observed to determine whether the concepts and directions were explained clearly and thoroughly. Additionally, individual students were invited to test the labs and contribute more specific feedback on the difficulty level of the content within the labs. This feedback stage will later be repeated with four more labs currently in the development stages.

The research for this thesis was involved in phase two of testing the Social Network theory and Locality theory labs. A modified Solomon-Four group design was used to determine which kind of lesson each of the eight science classrooms would receive (McGahee & Tingen, 2009). Four of the eight classrooms worked through the two labs online during class time. Two of those classes additionally received a survey both prior to and after the lesson, and two will receive only a post-survey. Finally, two comparison classes will receive only the two surveys, and two more will receive only the post-survey. The full text of the survey is included in Appendix A. The pre and post-surveys are identical, asking the student questions that determine their level of interest in and comfort with the field of computer science. This design was used to compare results categorized by the four group conditions to allow for potential assessment of differences due to the labs and the effect of the surveys on their knowledge and attitude.

The surveys included four sets of questions used to determine whether the completion of these interactive labs influence their perceptions of this field as an achievable and interesting field in which to work. The first set of questions asked students to rate their confidence level with different ideas surrounding their skill with the scientific process. The students rated their confidence on a four-point scale from "not at all confident" to "very confident." The second set of questions was designed to determine the reason a student believed they could or could not achieve a career in computer science or science in general. These open-ended responses provided insights into the students' perceptions about science and computer science beyond the closed-ended item questions in the rest of the survey. The third set of questions to rate their accordance with various statements about the field of computer science from "Strongly Disagree" to "Strongly Agree." These items were adapted from items shared on the AWE website (Marra & Bogue, 2008). The fourth section of survey questions gave information about the students' future goals in relation to expected education and career choices.

4.2 Hypotheses

The expected outcome of testing the labs is that students who take the lab experience a change in their perception of computer science. For example, a question on the survey given to the students is, "I can create a display to communicate my data and observations." It is hypothesized that students who did not take the labs would have no discernable change from the pre-survey to the post-survey. Similarly, students who took the labs would have a discernable change from pre-survey to post-survey. Students who selected "not at all confident" for these questions are expected to move to "not very confident," "somewhat confident," or "very confident." Students who selected "not very confident" would move to "somewhat confident" or "very confident." Students who selected "somewhat confident" would move to "very confident."

It is expected that the number of students who move in the positive direction is greater than the number of students who move in the negative direction for those who took the lab. These values are expected to remain unchanged for students who did not take the lab. There are identical hypotheses for all questions on the front page of the survey, which can be found in Appendix A, as well as all questions in the "About Me" section. For the remaining questions in the "What Computer Scientists Do" section, these same movements are expected for questions 3, 5, 6, and 7 as seen in Appendix A.

4.3 Description of the Participants

The classes that participated included eighth grade biology, early high school math, and a computer introduction class. None of these were identified by the teachers as part of the Honors program nor were any considered to be part of a special science or engineering curriculum. Additionally, none of the participating students had been exposed to or had extensive experience with any programming languages. The reliability ratings of student responses to the survey questions were relatively high for all sections in the survey (Titcomb).

4.4 Results

The analysis of student responses across experimental conditions did not reveal many systematic changes in students' perception of computer science. For certain questions, the analysis indicates there may have been positive changes; however, there were an equal number that suggest students were frustrated with the classroom conditions described later in Section 4.5. The control group responses presented a challenge as well in that some of the students in the comparison group who did not experience the online labs were disappointed in not participating in this portion of the study. Additionally, some of the open-ended responses to the embedded questions revealed that some of the younger students did not consistently participate in a professional manner. However, this can also be interpreted as an indication of the limited patience many students felt due to Internet connectivity issues that arose during a portion of the study.

For the students who completed labs, the hypothesized direction of a change in survey response would be positive as described in Section 4.2. Overall, a majority of the questions registered no change in responses from the pre-survey to the post-survey; 50%–86% of the students showed no change. Although a portion of the items also showed support for the hypothesis, an equivalent number of items showed results to the contrary.

In the open-ended portion of the survey, students described their inclination and reasoning toward becoming a scientist or computer scientist. Many students supported their response of "no" to computer scientist with "I am not good with computers." In addition, there was a strong general interest in other sciences such as chemistry and biology. Computer scientists were often negatively characterized as isolated and "being in front of a computer all day." The students who answered "no" often did not feel that they had a clear understanding of what specific tasks computer scientists were required to do. This was not an unexpected answer since the labs are designed to familiarize students with a theory within the field of computer science rather than give them specific tasks to complete as an acting computer scientist during the lesson. Students who felt they could become a computer scientist in the future often cited previous computing experience or programming experience as a reason they are considering this field.

4.5 Process Challenges

Conducting this experiment in the setting of school classrooms presents an intricate set of challenges that should be noted. Schools often have computer equipment that may contain software that is either incompatible with the online program, or does not have the necessary update to run the program properly. For example, Java was required to run the labs and some students were not able to enable it on their machines. Based on similar issues during Phase one of testing these labs, the Principal Investigator went to the sites prior to experimentation and attempted to pre-load the software needed to run the labs. Despite this effort, difficulties were still encountered. Another feature that presented an issue was Internet connectivity. One of the schools utilized wireless Internet and laptop computers and another utilized wired connections from desktop computers. Both of these versions presented unique challenges for completion of the online labs. Despite design changes to minimize bandwidth used by the online lab process, the setup time required by the lab was still not ideal for some students. A final issue was that some students were unable to finish due to limited battery power. If a previous class had used the laptop, it may not have had enough recharging time to accommodate the full length of time needed to complete the labs.

A non-technical challenge was also experienced during the second day of experimentation when a class was interrupted by a school announcement on the public address systems asking a set of students to leave class and report for another meeting. For that class, over half of the students were not able to complete the lab.

With these challenges, it is unclear what effect the participation in these online labs had on students' perceptions of computer science. Middle and high school classrooms are unpredictable work environments, and future labs need to be more flexible in how they allow student interaction. Additionally, the level of difficulty presented in the lab needs to be more consistent with the grade level in which the lab is being tested. Once the proposed changes have been made, the labs should be tested again in a more controlled classroom setting at several different grade levels to determine their affect on students' perceptions.

To address these difficulties experienced in the lab environment, we felt that changes to the development process of the apparatuses and labs were necessary.

5. Changes to the Development Process

Each lab requires a short amount of time, usually between 50 and 90 minutes. During this period, not only do the concepts surrounding the theory need to be introduced, all functionality of the lab notebook and apparatuses need to be explained as well.

5.1 Apparatus GUI Variant

Many apparatuses were developed as a part of class projects where the main goal was to provide as much functionality as possible for use in many future labs. These apparatuses are very flexible in the ways they can be used in new and existing labs, but many students expressed confusion with the interfaces of these new tools throughout the testing process even after viewing the short tutorials included in the labs. To make the apparatus interface more intuitive, especially for younger students, all future apparatuses should have the option to hide non-essential buttons, options, and other visual displays. For example, the QueueSim apparatus offers several functions similar to an online video player. The student can fast forward and backward through the simulation as well as increase and decrease the speed so that each stage can be seen and re-examined if necessary. However, the only buttons that the student needs for easy completion of the lab are the start and skip-to-end buttons.

To accommodate this change, the code has been modified for the lab author to specify in their XML tags exactly which buttons and displays make sense for the lab they are creating. For example, the following XML tag will open an instance of the QueueSim apparatus within the lab.

```
<options>
      <searchBar enable="true" canChange="false"/>
      <seekButtons enable="false"/>
      <optionsTabEnable enable="true"/>
```

```
    <defaultView canChange="false" view="store"/>
    <customerItems rangeLower="1" rangeUpper="5" mean="3"
          distribution="uniform" canChange="false"
          showDistribution="false"/>
    <arrivalRate rangeLower="1" rangeUpper="5" mean="2"
          distribution="poisson" canChange="false"
          showDistribution="false"/>
    <servers number="4" canChange="false" speed="3"/>
    <lines onePerServer="true" canChange="false"/>
    <animationSpeed defaultSpeedUp="1" minMultiplier="4"
          maxMultiplier="4"/>
</options>
```

There are several options available for this apparatus, but the ones to be noted are the lines with "`searchBar`," "`seekButtons`", and "`optionsTabEnable`" listed. These three options allow the lab author to turn on or off a majority of the visual features that offer secondary functionality. When all three of these options are not enabled, QueueSim appears with a very simple interface with only one button for the student to choose, making the objective of the apparatus much more clear.

With these changes, it will be more obvious to the student what needs to take place as soon as the apparatus is opened even without a tutorial. Since there is less to understand visually, it is less overwhelming for a student's first experience with a theory in computer science, and they are less likely to associate negative feelings with their difficulty in operating the apparatus and, by extension, their ability to work with computers. Additionally, this flexibility in display allows apparatuses, the most intricate part of the lab structure, to be reused more often in new ways because the lab author can customize the buttons shown and statistics displayed to work with new labs.

5.2 Lab Plans

Several ages were included in the testing process, ranging from eighth to twelfth grade. From the open-ended responses, it was apparent that the students' perceptions of their ability to become a computer scientist were set by the time they reached these grade levels. For this reason, it is suggested that younger audiences be targeted with these labs. Additionally, the difficulties with the content encountered by the students often varied depending on the prior knowledge and experience of each student. In the development of future labs, each should have four different versions that each appeal to a specific grade level or amount of prior knowledge. The levels that will be targeted are middle school, early high school, late high school and honors classes, and early college.

The process of writing a lab was previously left up to the lab author. Many labs and apparatuses were also created as a part of class projects or theses, so they required extensive functionality and coverage of the theory. A wide range of people have been involved in the content development of these labs, and a standardized method of creation is necessary to encourage consistency in the types of concepts covered within the labs. It is now apparent that significant detail in the labs operated by younger students is overwhelming for one class period. To ensure that a lab fits the needs of each grade level, the development process has been broken into smaller milestones to be submitted in a specific format, called a lab plan. An example of this lab plan for the Little's Law lab can be found in Appendix B.

The first step in this process is to create a complete list of topics that would fit into an all-encompassing lab for a particular theory. These topics are listed as open-ended questions that either the lab will or address or the student will answer by discovery. Next, individual lab outlines are created for each of the four targeted grade levels: middle school, early high school, late high school, and introductory college. Since students work these labs on individually, each individual learning goal that is covered in the lab needs detailed explanation and longer time to sink in. The individual lab outline for each grade level should begin with a list of topics from the overall topic list to be covered specifically in this lab. For example, the middle school lab should have a maximum of four major concepts that are introduced, and each topic should have a minimum of five minutes devoted to explanation and exploration. The labs tested in the high schools worked through approximately ten central concepts. Although each of these concepts were all relevant to the topic of the lab, the students' feedback and short answers indicated that they did not gain enough experience with them to be able to answer the higher-level application questions as thoroughly as anticipated.

To ensure students achieve maximal comprehension of each topic, a middle school lab should focus on very few core concepts, each of which should require no prior knowledge beyond the basics of arithmetic. Once the middle school list is set, further topics can be appended for the remaining grade levels. In addition to the topic list, the individual lab outline should also specify how apparatuses will be used in the lab. Each apparatus has a variety of functionality options, and the lab outline will need to specify which parts of the apparatus interface (GUI variant) should be available to the student at that level. As few options as possible should be chosen so that the lab does not spend a majority of its time instructing students on the operation of the apparatus rather than using it for experimentation.

The final component of the lab plan is the lesson plan for each grade level. The lesson plan section provides an outline for every page in the lab. The "Section" column indicates which part of the lab this slide is in, preliminary, experimentation, or evaluation. Between each section, there should also be a transition slide containing a summary of the previous section. These are used as breaking points in the event the lab needs to be ended early or restarted at a later date. The second column in the lesson plan is the duration of that slide. Each row in the table can represent 1–2 slides, and the time stated in the duration cell is an approximation of the length of time available for a student to work through this section. As the labs are tested upon completion, the content can be adjusted to better match these limits. The third column contains the learning goal of each slide. Here, the author briefly describes what the student is supposed to take away from this section. Upon review of the completed lab, this column makes it easier for a colleague to judge whether this portion of the lab contains the necessary information. Finally, the fourth column contains a more detailed explanation of what will be covered in each slide. Although it does not contain the full text of the slide, it will describe how this portion of the lab will answer the answer posed in the "Learning Goal" field. This field will also describe when and how a student will use each apparatus.

6. Implementation of the Development Process

This new process of lab development was used in the creation of the Little's Law labs. These labs walk a student through the main concept of queues and how different factors in the simulation fit together. The student will study the relationship between average number of customers in a queue, average wait time in the queue, and the average arrival rate of the customers in the context of a grocery store. The first lab that was created for this series was for the late high school level. In this version, explanation of apparatus usage and mathematical processes are very minimal in comparison to what can be found in the middle school lab.

As seen in Figure 6.1, each lab begins with a welcome screen; the student types in their name or student code depending on what is required from their teacher. Basic instructions and a welcome message are also visible on the chalkboard in the upper right corner. In the bottom right, there is a window called the "Lab Bench" that will hold links to all apparatuses that the student will be using throughout the lab.

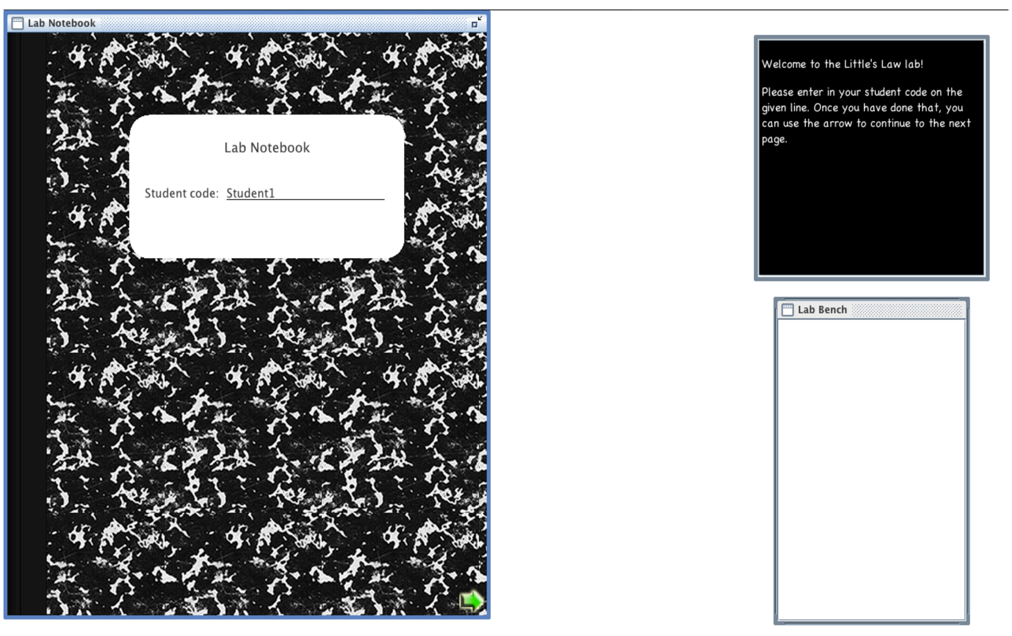

Figure 6.1

Figure 6.2 shows a page from the preliminary section. This area walks students through the relationship between the three concepts and how changes in each might affect the simulation. Later in the lab, the student will run the simulation of a grocery store queue using the QueueSim apparatus, as shown in Figure 3.2. The data generated will be available to look at using the Spreadsheet apparatus as shown in Figure 3.1. With these apparatuses available, the student will learn to calculate the average waiting time and the average arrival rate.

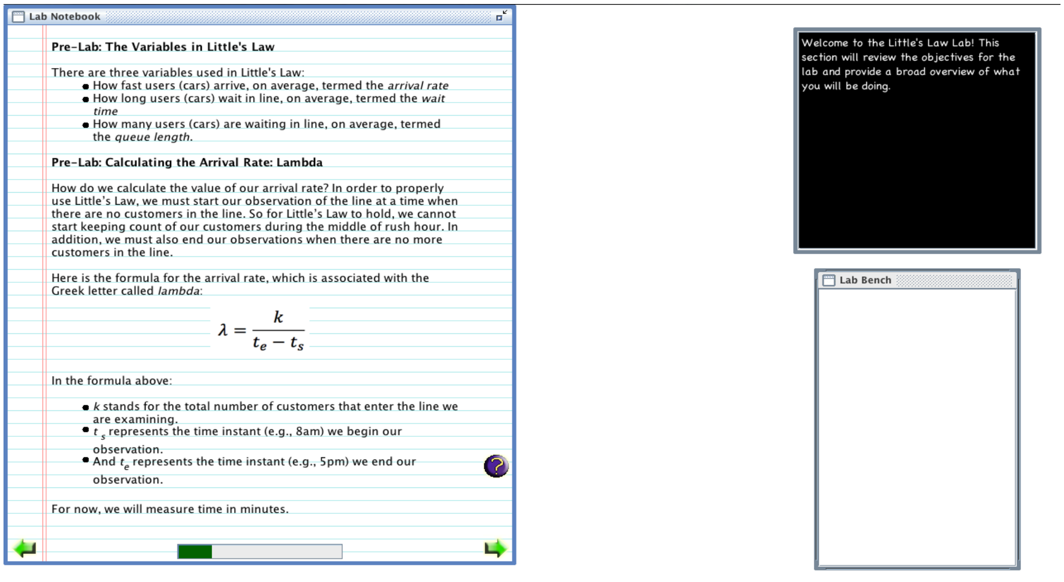

Figure 6.2

In the experimentation section of the lab, the student will analyze the equation that relates these three variables. They will run the QueueSim simulation twice, using preset values for two of the variables each time. Based on the data generated from the simulation, the student will calculate the third variable to determine whether or not the relationship described by Little's Law hold true for this scenario. In the final section, the student will summarize what they have learned and answer questions based on the material presented throughout the lab as seen in Figure 6.3. In addition, a final applications section was included in this lab for students to review once they have completed the lab if time permits. In this case, now that the student understands the basics behind the theory of queues in the context of a grocery store, they will be able to read about how this theory is applied in computer science to network design.

7. Summary and Conclusion

Enrollment in computer science is currently lower than job prospects would indicate. A factor of low enrollment rate is that students often misperceive this field as solely programming. Computer science classes offered in middle and high schools often cover only the basics of programming principles. While programming is an important tool, the perception that computer science is only programming is harmful.

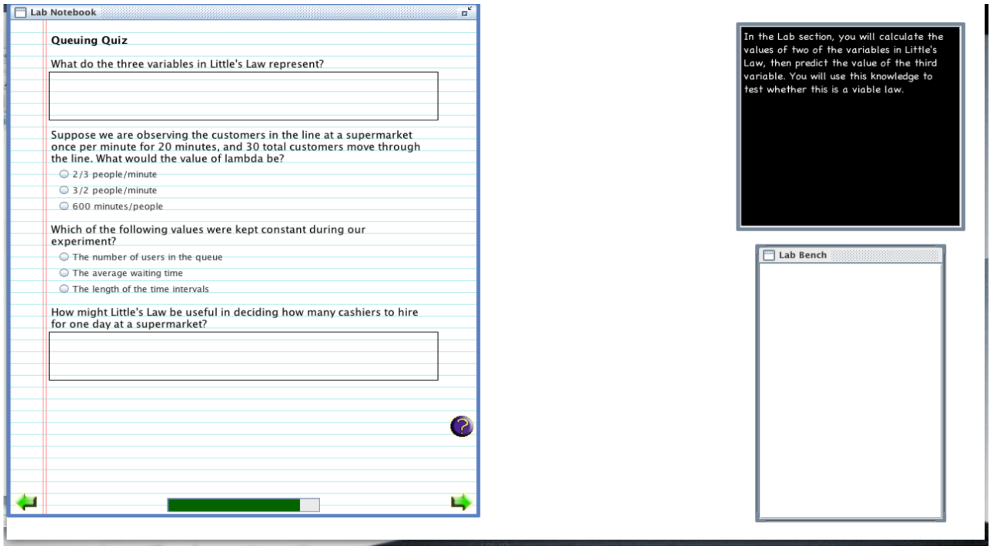

Figure 6.3

The focus of the LoCuS project has been the creation of the interactive online labs that will engage students in the underlying theories of computer science from an early age. As part of this research, results have been gathered from the study of students' change in perceptions in response to experience with these labs. Due to unforeseen environmental factors, statistically significant changes were not found in either the positive or negative direction of perceptions. However, the nature of the testing environment and the feedback received from the students throughout the study has prompted the need for design changes in the apparatuses and standardization of the lab authoring process. The inclusion of the GUI variant in each apparatus will allow greater flexibility in the use of these apparatuses in current and future labs. By allowing the lab author to control the complexity, the author can more closely tailor the difficulty level to the expected audience of the lab. The use of the lab plan in the development of the lab content will ensure greater similarity and consistent quality throughout the entire series of labs developed by the LoCuS project. At each transition slide described in the lesson plan for each lab, the student will have completed some exercise fit for evaluation so that the lesson can be temporarily ended but will still be fit for examination by a teacher.

As these labs are tested for effectiveness, they will also be made available for use to the public. With these more modular, accessible labs, students will be able to gain a better understanding of the basis of certain theories in computer science in the same way that a chemistry or biology lab piques students' interest form an early age. This early awareness and interest in a subject is a key factor in the development of their perceptions of the field later in life. Should these perceptions be positively affected by a students' interaction with these online labs, these students would be more likely to join the undermanned field of computer science at the college and professional level.

It was remarkable to see how the environmental factors so greatly affect the testing design. All my prior instructional and lesson planning experience has been in situations where I was able to plan and control every aspect of the learning environment in a college setting. Not only are the learning processes of younger students very different and more free form, middle and high school are very hectic places in which to work. The introduction of new concepts and tools in an unfamiliar medium like these interactive online labs proved to be very overwhelming for several students, and classroom management was a much larger factor in the testing environment than I expected.

In summary, this thesis research made the following contributions:

- The *Little's Law lab* was created and written to be presented to four different grade levels.
- The *Spreadsheet and QueueSim apparatuses* were refined to work more smoothly with the Little's Law lab.
- *Lab plans* were proposed to structure the presentation of concepts at different levels.
- The *effectiveness of labs* to change perceptions was tested at two schools in Tucson, AZ.
- *Refinements to the LoCuS infrastructure* were designed during project meetings over the previous 12 months.

8. Future Work

The set of labs concerning Little's Law and queuing theory will serve as an example of the division of topics into subgroups that are more manageable by each age group and time limit. Each of the previously constructed labs should be refactored into four separate labs directed at the designated grade levels so that the widest audience can be reached with each lab topic. With these more modular labs, the change in perception can be retested at each of these grade levels. With feedback from several age groups, it may become apparent when certain perceptions are formed or forethought is given to a potential choice of career.

9. Roles and Responsibilities

This research was conducted in the context of the Laboratory for Computer Science (LoCuS) project. Research assistant Tapasya Patki and later Andrey Kvochko were Chief Programmers for the project, responsible for coordinating the LoCuS infrastructure (principally the Java classes) into which the lab and apparatuses described here were integrated.

I wrote the Little's Law lab, benefitting from helpful comments and feedback from those listed above. I specified and developed the Spreadsheet apparatus with Livio de la Cruz as part of a CS335 Honors final project. I participated in specifying the QueueSim apparatus, which was implemented by Lane Simons, Matt Justice, Christopher Rogers, and Nathan Paulson, also as a CS335 Honors final project. Subsequently, I extended QueueSim and fixed minor issues in both apparatuses to ensure that they worked well with the lab. During this time, I also created three refinements of the Little's Law lab.

Allison Titcomb designed the survey instruments and the experimental methodology in discussion with Richard Snodgrass. When I joined the project, I participated in the final revision of the instruments. I helped Allison run the experiments in December 2011 at one of the middle schools, administering the lab and handling the details of collecting the surveys for two days. After the experiment, I consolidated the data from the online files that were automatically generated by the LoCuS infrastructure when the students submitted the labs. Allison performed the data analysis. I partially derived the discussion in Section 4 from Allison's initial write up of the testing. I wrote the entirety of the remainder of this thesis.

In March 2012, I attended the conference of the ACM Special Interest Group on Computer Science Education by invitation to present this work as well as a poster that I created in the Student Research Competition. Finally, I participated actively in many project meetings over the year (May 2011–May 2012) I worked on this project and honors research.

10. Acknowledgements

I would like to thank Dr. Richard Snodgrass for allowing me to collaborate with him on this project and for his guidance throughout the development process. Allison Titcomb has provided extensive assistance with the development of the test design and the analysis of the statistical results. Finally, I would like to thank my fellow graduate and undergraduate students Andrey Kvochko, Tapasya Patki, Drew Mahrt, Gavin Simmons, and Rob Trame for their continued support and assistance throughout this project. The LoCuS project is supported in part by NSF grants CNS-0938948 and IIS-1016205.

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12. Appendix A

CPATH Field Guide **Pre/Post** Questions

Please fill in the circle that tells how confident you currently feel you can use each of the following skills when you work on a science investigation.

	Not at all confident	**Not very confident**	**Somewhat confident**	**Very confident**
I can use scientific knowledge to form a question.	○	○	○	○
I can ask a question that can be answered by collecting data.	○	○	○	○
I can design a scientific procedure to answer a question.	○	○	○	○
I can communicate a scientific procedure to others.	○	○	○	○
I can record data accurately.	○	○	○	○
I can use data to create a graph for presentation to others.	○	○	○	○
I can create a display to communicate my data and observations.	○	○	○	○
I can analyze the results of a scientific investigation.	○	○	○	○
I can use science terms to share my results.	○	○	○	○
I can use "models" to explain my results.	○	○	○	○
I can use the results of my investigation to answer the question that I asked.	○	○	○	○

Do you think you could become a scientist? ❑ Yes ❑ No ❑ Not sure
Why or why not?

Do you think you could become a computer scientist? ❑ Yes ❑ No ❑ Not sure
Why or why not?

Read the following statements and indicate how much you disagree or agree.

Computer Scientists …	Strongly Disagree	Disagree	Agree	Strongly Agree	Don't Know
…write programs.	○	○	○	○	○
…design and build software systems.	○	○	○	○	○
…develop and test scientific theories.	○	○	○	○	○
…work on things to help the world.	○	○	○	○	○
…analyze experimental data.	○	○	○	○	○
…use models to explain how things that they build work.	○	○	○	○	○
…gather and analyze data to answer questions.	○	○	○	○	○

About me…	Strongly Disagree	Disagree	Agree	Strongly Agree	Don't Know
I have no interest in what computer scientists do.	○	○	○	○	○
I think I could pursue a career in a computer-related field.	○	○	○	○	○
I would like to study computer science in school.	○	○	○	○	○
I would like to know more about computer science careers.	○	○	○	○	○

More About Me…	
Gender	❑ Female ❑ Male
Current Grade Level in School	❑ 8th ❑ 9th ❑ 10th ❑ 11th ❑ 12th
Highest Degree I Expect to Earn	❑ High School Diploma ❑ Associates Degree ❑ Bachelor's Degree ❑ Master's Degree ❑ PhD or Professional Degree (e.g., MD, JD)

13. Appendix B

Lab Plan

Lab Theory: Little's Law

Name of Developer(s): Jaimie Sauls

Concept List:

1. What is a queue?
2. How can we use a simulation in place of observation?
3. What is the queuing simulator?
4. What is the average number of customers in a queue?
    a. What would a high/low average look like?
5. What is the average arrival rate?
    a. What real factors in the store might affect this rate?
    b. What would a high/low rate look like?
6. What is the average wait time in a queue?
    a. What would a high/low average wait look like?
    b. What real factors might affect this rate?
7. What is Little's Law?
    a. How does it relate the three above concepts?
    b. How can we use it to create predictions?
8. How do we find an average?
9. How do we calculate:
    a. The arrival rate in one minute?
    b. The wait time of one customer?
10. How do we calculate:
    a. The average number of customers in the queue over the whole simulation?
    b. The average arrival rate over the whole simulation?
    c. The average of the wait times for all customers?

Lab Outline: Middle School

Lab Duration: 50 minutes

Apparatus Name: QueueSim

GUI Options Needed:

- Play button
- Skip-to-end button
- Number of customers display
- Pre-set input files

Main Topic List

1. What is a queue?
2. How can simulations be used?
3. What is average arrival rate?
4. What is average wait time?

Lesson Plan: Middle School

Section	Duration	Learning Goal	Description
Preliminary	2 min.	What is a queue?	Short explanation. How does it relate to a grocery store?
	6 min.	How can a simulation be used?	Predict what may happen in a grocery store without observing a real one for several hours. *Show QueueSim with high arrival rate*. What was noticed about the average number of people in the lines? What problems might occur if this simulation continued for an entire day?
	3 min.	How do we use this simulation to make predictions?	What are some things that might affect the length of the queues in the store? Are these things the manager will have control over?
	6 min.	What is arrival rate?	Short explanation. How might the simulation change with a lower arrival rate*? Show QueueSim with lower rate.* What was affected by this change? What problems may occur?
Transition	2 min.	Summary of knowledge so far	Grocery store managers can use simulations like these to make

			predictions about busy lines. How might the length of time a customer spends in a queue affect overall number of customers? What would we expect to see in the simulation in this case?
Experiment	6 min.	What is wait time?	Short explanation. *Show QueueSim with high wait time*. What did you notice about the average number of customers waiting in line during the simulation? What do you expect will happen with a lower wait time?
	6 min.	Continued	*Show QueueSim with low wait time*. How was the simulation different? How many people were in the store on average? Were your predictions accurate? Why or why not?
Transition	2 min.	Summary and application of knowledge	Have seen how wait time and arrival rate affect the number of customers in the queue. What are other factors that might affect how long a customer spends in line? What are some things you could do in your store to decrease the average wait time?
Evaluation	3 min.	Connections between arrival rate and wait time simulations	We have seen high/low average customer arrival rate and high/low average customer wait time. Which of these scenarios had similar effects on the average number of customers in the queue? Why might this be?
	6 min.	Quiz section	Short answer and multiple-choice questions.
Extra: Application	3 min.	How is this used in the real world?	Relating queues to toll bridge management and server queues in a network.

Lab Outline: Early High School

Lab Duration: 50 minutes

Apparatus Name: QueueSim

GUI Options Needed:

- Play button
- Skip-to-end button
- Number of customers display
- Wait time display
- Pre-set input files

Main Topic List

1. What is a queue?
2. How can simulations be used?
3. What is average arrival rate?
4. What is average wait time?
5. What is Little's Law?

Lesson Plan: Early High School

Section	Duration	Learning Goal	Description
Preliminary	2 min.	What is a queue?	Short explanation. How does it relate to a grocery store?
	4 min.	How can a simulation be used?	Predict what may happen in a grocery store without observing a real one for several hours. *Show QueueSim with high arrival rate*. What was noticed about the average number of people in the lines? What problems might occur if this simulation continued for an entire day?
	3 min.	How do we use this simulation to make predictions?	What are some things that might affect the length of the queues in the store? Are these things the manager will have control over?
	4 min.	What is arrival rate?	Short explanation. How might the simulation change with a lower arrival rate*? Show QueueSim with lower rate.* What was affected by this change? What problems may occur?

	4 min.	What is wait time?	Short explanation. *Show QueueSim with high wait time*. What did you notice about the average number of customers waiting in line during the simulation? What do you expect will happen with a lower wait time?
Transition	2 min.	Summary of knowledge so far	Grocery store managers can use simulations like these to make predictions about busy lines. How might the length of time a customer spends in a queue affect overall number of customers? What about average wait time?
Experiment	8 min.	What is Little's Law?	Short explanation. What is the equation? How does this relate to the simulations we saw before? How can we use the simulation to get these values? How might we use this formula to predict one of the values?
	8 min.	Continued	*Show QueueSim with low wait time with average number of customers and wait time displayed.* How did these two values change over time? What do we expect the average arrival rate to be? Is this correct?
Transition	2 min.	Summary and application of knowledge	Have can we use Little's Law to predict one value given the other two?
Evaluation	3 min.	Connections between arrival rate and wait time simulations	We have seen high/low average customer arrival rate and high/low average customer wait time. Which of these scenarios had similar effects on the average number of customers in the queue? Why might this be?
	6 min.	Quiz section	Short answer and multiple-choice questions.
Extra: Application	3 min.	How is this used in the real world?	Relating queues to toll bridge management and server queues in a network.

Lab Outline: Late High School and Honors Classes

Lab Duration: 50 minutes

Apparatus Name: QueueSim

GUI Options Needed:

- Play button
- Skip-to-end button
- Number of customers display
- Wait time display
- Pre-set input files

Apparatus Name: Spreadsheet

GUI Options Needed:

- New Calculated Row Tab
    - Average Calculation
- QueueSim connection
- Pre-set input files

Main Topic List

1. What is a queue?
2. How can simulations be used?
3. What is average arrival rate?
    a. How can we calculate this?
4. What is average wait time?
5. What is Little's Law?

Lesson Plan: Late High School and Honors Classes

Section	Duration	Learning Goal	Description
Preliminary	2 min.	What is a queue?	Short explanation. How does it relate to a grocery store?
	4 min.	What is wait time?	Short explanation. How might the simulation change with a low wait time*? Show QueueSim with low wait time.* What was affected by this change? What problems may occur?
	3 min.	What is arrival rate?	Short explanation. *Show QueueSim with high arrival rate*. What did you notice about the average number of customers waiting in line during the simulation? What do you expect will happen with a lower rate?
	5 min.	How do we calculate arrival	*Open spreadsheet with sample number of people that arrive*

		rate?	*each minute of a simulation.* How would we calculate the average number of people that arrive each minute?
Transition	2 min.	Summary of knowledge so far	Grocery store managers can use simulations like these to make predictions about busy lines. How might the length of time a customer spends in a queue affect overall number of customers? What about average wait time? What information do we need to calculate arrival rate?
Experiment	6 min.	What is Little's Law?	Short explanation. What is the equation? How does this relate to the simulations we saw before? How can we use the simulation to get these values? How might we use this formula to predict one of the values?
	10 min.	Continued	*Show QueueSim with low wait time with average number of customers and wait time displayed.* How did these two values change over time? What do we expect the average arrival rate to be? *Use Spreadsheet to calculate the arrival rate.* Is this what we expected?
Transition	2 min.	Summary and application of knowledge	Have can we use Little's Law to predict one value given the other two?
Evaluation	3 min.	Connections between arrival rate and wait time simulations	We have seen high/low average customer arrival rate and high/low average customer wait time. Which of these scenarios had similar effects on the average number of customers in the queue? Why might this be?
	6 min.	Quiz section	Short answer and multiple-choice questions.
Extra: Application	3 min.	How is this used in the real world?	Relating queues to toll bridge management and server queues in a network.

Lab Outline: Early College

Lab Duration: 90 minutes

Apparatus Name: QueueSim
GUI Options Needed:
- Play button
- Skip-to-end button
- Number of customers display
- Wait time display
- Pre-set input files
- Dot version

Apparatus Name: Spreadsheet
GUI Options Needed:
- New Calculated Row Tab
    - Average Calculation
- New Calculated Column Tab
    - Subtraction Calculation
- QueueSim connection
- Pre-set input files

Main Topic List

1. What is a queue?
2. How can simulations be used?
3. What is average arrival rate?
    a. How can we calculate this?
4. What is average wait time?
    a. How can we calculate this?
5. What is Little's Law?

Lesson Plan: Early College

Section	Duration	Learning Goal	Description
Preliminary	2 min.	What is a queue?	Short explanation. How does it relate to a grocery store?
	5 min.	What is wait time?	Short explanation. How might the simulation change with a low wait time? *Show QueueSim with low wait time.* What was affected by this change? What problems may occur?
	8 min.	How can we calculate average wait time?	How can we calculate the wait time for one customer? *Show Spreadsheet with start/end times of 5 customers.* How can we calculate the average wait time

			for all of these customers? *Continue on same Spreadsheet.*
	5 min.	What is arrival rate?	Short explanation. *Show QueueSim with high arrival rate*. What did you notice about the average number of customers waiting in line during the simulation? What do you expect will happen with a lower rate?
	8 min.	How do we calculate arrival rate?	*Open spreadsheet with sample number of people that arrive each minute of a simulation.* How would we calculate the average number of people that arrive each minute?
Transition	2 min.	Summary of knowledge so far	Grocery store managers can use simulations like these to make predictions about busy lines. How might the length of time a customer spends in a queue affect overall number of customers? What about average wait time? What information do we need to calculate arrival rate and wait time?
Experiment	6 min.	What is Little's Law?	Short explanation. What is the equation? How does this relate to the simulations we saw before? How can we use the simulation to get these values? How might we use this formula to predict one of the values?
	10 min.	Continued	*Show QueueSim with high arrival rate with average number of customers and arrival rate displayed*. How did these two values change over time? What do we expect the wait time to be? *Use Spreadsheet to calculate arrival rate of customers.* Is this what we expected?
	10 min.	Continued	*Show QueueSim with low wait time with average number of customers and wait time displayed.* How did these two

			values change over time? What do we expect the average arrival rate to be? *Use Spreadsheet to calculate the arrival rate.* Is this what we expected?
Transition	2 min.	Summary and application of knowledge	Have can we use Little's Law to predict one value given the other two? What information do we need to calculate the values of the variables in the formula?
Evaluation	6 min.	Connections between arrival rate and wait time simulations	We have seen high/low average customer arrival rate and high/low average customer wait time. Which of these scenarios had similar effects on the average number of customers in the queue? Why might this be?
	6 min.	Quiz section	Short answer and multiple-choice questions.
Extra: Application	15 min.	How is this used in the real world?	Relating queues to toll bridge management and server queues in a network. Extended discussion of application to queues. *Show QueueSim with dot version*. Show picture of network with similar layout. How can Little's Law be applied here to optimize the server?